MOTOROLA

DL128/D
REV 6

# Analog/Interface ICs

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REV 6

# Analog ICs

## Device Data

## Vol. II

This publication presents technical information for the broad line of Analog and Interface Integrated Circuit products. Complete device specifications are provided in the form of **Data Sheets** which are categorized by product type into ten chapters for easy reference. **Selector Guides** by product family are provided in the beginning of each chapter to enable quick comparisons of performance characteristics. A **Cross Reference** chapter lists Motorola nearest replacement and functional equivalent part numbers for other industry products.

One chapter is devoted showing all of the **Tape and Reel Options**. All **Packaging Information**, including surface mount packages, is provided in another chapter.

Additionally, chapters are provided with information on **Quality and Reliability Assurance** program concepts, high–reliability processing, and abstracts of available **Applications and Product Literature**.

The information in this book has been carefully checked and is believed to be accurate; however, no responsibility is assumed for inaccuracies.

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# Alphanumeric Index and Cross References

## In Brief . . .

Motorola Analog and Interface Integrated Circuits cover a much broader range of products than the traditional op amps/regulators/consumer–image associated with Analog suppliers. Analog circuit technology currently influences the design and architecture of equipment for all major markets. As with other integrated circuit technologies, Analog circuit design techniques and processes have been continually refined and updated to meet the needs of these diversified markets.

Operational amplifiers have utilized JFET inputs for improved performance, plus innovative design and trimming concepts have evolved for improved high performance and precision characteristics. In analog power ICs, basic voltage regulators have been refined to include higher current and voltage levels, low dropout regulators, and more precise three–terminal fixed and adjustable voltages. The power area continues to expand into switching regulators, power supply control and supervisory circuits, motor controllers, and battery charging controllers.

Analog designs also offer a wide array of line drivers, receivers and transceivers for many of the EIA, European, IEEE and IBM interface standards. Peripheral drivers for a variety of devices are also offered. In addition to these key interface functions, hard disk drive read channel circuits, 10BASE–T and Ethernet circuits are also available.

In Data Conversion, a high performance video speed flash converter is available, as well as a variety of CMOS and Sigma–Delta converters. Analog circuit technology has also provided precision low–voltage references for use in Data Conversion and other low temperature drift applications.

A host of special purpose analog devices have also been developed. These circuits find applications in telecommunications, radio, television, automotive, RF communications, and data transmission. These products have reduced the cost of RF communications, and have provided capabilities in telecommunications which make the telephone line convenient for both voice and data communications. Analog developments have also reduced the many discrete components formerly required for consumer functions to a few IC packages and have made significant contributions to the rapidly growing market for electronics in automotive applications.

The table of contents provides a perspective of the many markets served by Analog/Interface ICs and of Motorola's involvement in these areas.

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# = Not recommended for new designs.

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# = Not recommended for new designs.

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| MC34012 | Telephone Tone Ringer | * |
| MC34014 | Telephone Speech Network with Dialer Interface | * |
| MC34016 | Cordless Universal Telephone Interface | * |
| MC34017 | Telephone Tone Ringer | * |
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* = See Communications Device Data (DL136).
# = Not recommended for new designs.

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| TCA3388 | Telephone Speech Network | * |
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* = See Communications Device Data (DL136).
# = Not recommended for new designs.

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| UC3844B | HIgh Performance Current Mode Controller | 3–785 |
| UC3845 | HIgh Performance Current Mode Controller | 3–772 |
| UC3845B | HIgh Performance Current Mode Controller | 3–785 |
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* = See Communications Device Data (DL136).
# = Not recommended for new designs.

# Cross References

The following table represents a cross reference guide for all Analog devices that are manufactured by Motorola. Where the Motorola part number differs from the industry part number, the Motorola device is a "form, fit and function" replacement for the industry part number. However, some differences in characteristics and/or specifications may exist.

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| 75175 | SN75175 | |
| 9636AT | MC3488AP | |
| 9640PC | MC26S10P# | |
| 9667PC | MC1413P | |
| 9668PC | MC1416P | |
| AD589J | | LM385Z–1.2 |
| AD589K | | LM385Z–1.2 |
| AD589L | | LM385Z–1.2 |
| AD589M | | LM385BZ–1.2 |
| AM201AD | | LM201AN |
| AM201D | | LM201AN |
| AM26LS30P | AM26LS30PC | |
| AM26LS31CJ | AM26LS31PC# | |
| AM26LS31CN | AM26LS31PC# | |
| AM26LS32ACJ | AM26LS32D# | |
| AM26LS32ACN | AM26LS32PC# | |
| AM26LS32PC | AM26LS32PC# | |
| AM723PC | MC1723CP | |
| AN5150 | | MC34129P |
| CA081AE | | TL081ACP |
| CA081E | | TL081CP |
| CA082AE | | TL082ACP |
| CA082E | | TL082CP |
| CA084AE | | TL084ACN |
| CA084E | | TL084CN |
| CA1391E | MC1391P | |
| CA1458S | MC1458CP1 | |
| CA239AE | LM239AN | |
| CA239E | LM239N | |
| CA3026 | | CA3054 |
| CA3045F | | MC3346P |
| CA3046 | MC3346P | |
| CA3054 | CA3054 | |
| CA3058 | | CA3059 |
| CA3059 | CA3059 | |
| CA3079 | CA3079 | |
| CA3086F | | MC3346P |
| CA3136A | | MC3346P |
| CA3146 | | MC3346P |
| CA339AE | LM339AN | |
| CA339E | LM339N | |
| CA723CE | MC1723CP | |
| CA741CS | MC1741CP1 | |
| CS2842AD | UC2842BD1 | |
| CS2843AD | UC2843BD1 | |
| CS2844D | UC2844BD1 | |
| CS2845D | UC2845BD1 | |
| CS3842AD | UC3842BD1 | |
| CS3843AD | UC3843BD1 | |
| CS3844D | UC3844BD1 | |
| CS3845D | UC3845BD1 | |
| DM8822N | | MC1489AP |
| DS1233M | | MC34064P–5 |
| DS1488N | MC1488P | |
| DS1489AN | MC1489AP | |
| DS1489N | MC1489P | |
| DS26LS32N | AM26LS32P# | |
| DS26S10CN | MC26S10P# | |
| DS3650N | MC3450P# | |
| DS8834N | | MC8T26AP |
| DS8835N | | MC8T26AP |
| DS9636ACN | MC3488AP1 | |
| ICL741CLNPA | | MC1741CP1 |
| ICL741CLNTY | | MC1741CP1 |
| ICL8008CPA | | LM301AN |
| ICL8008CTY | | LM301AN |
| ICL8017CTW | | LM301AN |
| ICL8017MTW | | LM301AN |
| ICL8069CCZR | | LM385BZ–1.2 |
| ICL8069DCZR | | LM385BZ–1.2 |
| IP33063N | MC33063AP1 | |
| IP34060AN | MC34060AP | |
| IP34063N | MC34063AP1 | |
| IP3525AN | SG3525AN | |
| IP3526N | SG3526N | |
| IP3527AN | SG3527AN | |
| LM240LAZ–18 | | MC78L18ACP |
| LM240LAZ–24 | | MC78L24ACP |
| LM240LAZ–5.0 | | MC78L05ACP |
| LM240LAZ–6.0 | | MC78L05ACP |
| LM240LAZ–8.0 | | MC78L08ACP |
| LM249N | | MC4741CP |
| LM2575 | LM2575 | |
| LM258D | LM258D | |
| LM258M | LM258D | |
| LM258N | LM258N | |
| LM285Z–1.2 | LM285Z–1.2 | |
| LM285Z–2.5 | LM285Z–2.5 | |
| LM2901D | LM2901D | |
| LM2901M | LM2901D | |
| LM2901N | LM2901N | |
| LM2902D | LM2902D | |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| IP494ACJ | | TL594IN |
| IP494ACN | | TL594CN |
| IR3M03A | | MC34063AP1 |
| IR3M03AN | | MC34063AD |
| ITT3710 | | MC1391P |
| ITT656 | MC1413P | |
| L144AP | | LM324N |
| L203 | MC1413P | |
| L387 | | MC33267T |
| LF347BN | LF347BN | |
| LF347N | LF347N | |
| LF351BN | | MC34001BP |
| LF351N | LF351N | |
| LF353AN | MC34002AP | |
| LF353BN | MC34002BP | |
| LF353D | LF353D | |
| LF353N | LF353N | |
| LF411CD | LF411CD | |
| LF412CD | LF412CD | |
| LF441CD | LF441CD | |
| LF441CN | LF441CN | |
| LF442CD | LF442CD | |
| LF442CN | LF442CN | |
| LF444CD | LF444CD | |
| LF444CN | LF444CN | |
| LM11CLN | LM11CLN | |
| LM11CN | LM11CN | |
| LM139N | MC1391P | |
| LM1489AN | MC1489AP | |
| LM1489N | MC1489P | |
| LM1496N | MC1496P | |
| LM1496M | MC1496D | |
| LM1889 | | MC1374P |
| LM1981 | | MC13020P |
| LM201AD | LM201AD | |
| LM201AN | LM201AN | |
| LM201AP | | LM201AN |
| LM211D | LM211D | |
| LM211M | LM211D | |
| LM224D | LM224D | |
| LM224M | LM224D | |
| LM224N | LM224N | |
| LM239AN | LM239AN | |
| LM239D | LM239D | |
| LM239M | LM239D | |
| LM239N | LM239N | |
| LM240LAZ–12 | | MC78L12ACP |
| LM240LAZ–15 | | MC78L15ACP |
| LM2902M | LM2902D | |
| LM2902N | LM2902N | |
| LM2903D | LM2903D | |
| LM2903M | LM2903D | |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| LM2903N | LM2903N | |
| LM2903P | LM2903N | |
| LM2904M | LM2904D | |
| LM2904N | LM2904N | |
| LM2905N | | MC1455P1 |
| LM2931AD–5.0 | LM2931AD–5.0 | |
| LM2931AT–5.0 | LM2931AT–5.0 | |
| LM2931AZ–5.0 | LM2931AZ–5.0 | |
| LM2931CD | LM2931CD | |
| LM2931CM | LM2931CD | |
| LM2931CT | LM2931CT | |
| LM2931D–5.0 | LM2931D–5.0 | |
| LM2931D | LM2931D–5.0 | |
| LM2931T–5.0 | LM2931T–5.0 | |
| LM2931Z–5.0 | LM2931Z–5.0 | |
| LM2935T | LM2935T | |
| LM293D | LM293D | |
| LM301AD | LM301AD | |
| LM301AM | LM301AD | |
| LM301AN | LM301AN | |
| LM301AP | | LM301AN |
| LM3045 | | MC3346P |
| LM3046N | MC3346P | |
| LM3054 | CA3054 | |
| LM308AD | LM308AD | |
| LM308AN | LM308AN | |
| LM308P | | MC3356P |
| LM311D | LM311D | |
| LM311M | LM311D | |
| LM311N | LM311N | |
| LM311P | LM311N | |
| LM3146A | | MC3346P |
| LM3146 | | MC3346P |
| LM317KC | LM317T | |
| LM317KD | | LM317T |
| LM317LD | LM317LD | |
| LM317LZ | LM317LZ | |
| LM317MP | | LM317MT |
| LM317P | | LM317T |
| LM317T | LM317T | |
| LM3189 | | MC3356P |
| LM320LZ–12 | | MC79L12ACP |
| LM320LZ–15 | | MC79L15ACP |
| LM320LZ–5.0 | | MC79L05ACP |
| LM320MP–12 | | MC7912CT |
| LM320MP–15 | | MC7915CT |
| LM320MP–18 | | MC7918CT |
| LM320MP–24 | | MC7924CT |
| LM340LAZ–5.0 | | MC78L05ACP |
| LM340LAZ–8.0 | | MC78L08ACP |
| LM340T–12 | LM340T–12 | |
| LM340T–15 | LM340T–15 | |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| LM320MP–5.0 | | MC7905CT |
| LM320MP–5.2 | | MC7905.2CT |
| LM320MP–6.0 | | MC7906CT |
| LM320MP–8.0 | | MC7908CT |
| LM320T–12 | | MC7912CT |
| LM320T–15 | | MC7915CT |
| LM320T–5.0 | | MC7905CT |
| LM320T–5.2 | | MC7905.2CT |
| LM322N | | MC1455P1 |
| LM323AT | LM323AT | |
| LM323T | LM323T | |
| LM324AD | LM324AD | |
| LM324AN | LM324AN | |
| LM324D | LM324D | |
| LM324M | LM324D | |
| LM324N | LM324N | |
| LM337MP | | LM337MT |
| LM337MT | LM337MT | |
| LM337T | LM337T | |
| LM339AD | LM339AD | |
| LM339AM | LM339AD | |
| LM339AN | LM339AN | |
| LM339D | LM339D | |
| LM339N | LM339N | |
| LM339P | | LM339N |
| LM340AT–12 | LM340AT–12 | |
| LM340AT–15 | LM340AT–15 | |
| LM340AT–5.0 | LM340AT–5.0 | |
| LM340KC–12 | LM340T–12 | |
| LM340KC–15 | LM340T–15 | |
| LM340LAZ–12 | | MC78L12ACP |
| LM340LAZ–18 | | MC78L18ACP |
| LM340LAZ–24 | | MC78L24ACP |
| LM340T–18 | LM340T–18 | |
| LM340T–24 | LM340T–24 | |
| LM340T–5.0 | LM340T–5.0 | |
| LM340T–6.0 | LM340T–6.0 | |
| LM340T–8.0 | LM340T–8.0 | |
| LM341P–12 | | MC78M12CT |
| LM341P–15 | | MC78M15CT |
| LM341P–18 | | MC78M18CT |
| LM341P–24 | | MC78M24CT |
| LM341P–5.0 | | MC78M05CT |
| LM341P–6.0 | | MC78M06CT |
| LM341P–8.0 | | MC78M08CT |
| LM342P–12 | | MC78M12CT |
| LM342P–15 | | MC78M15CT |
| LM342P–18 | | MC78M18CT |
| LM342P–24 | | MC78M24CT |
| LM342P–5.0 | | MC78M05CT |
| LM342P–6.0 | | MC78M06CT |
| LM342P–8.0 | | MC78M08CT |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| LM348D | LM348D | |
| LM348M | LM348D | |
| LM349N | | MC4741CP |
| LM350T | LM350T | |
| LM358AN | | LM358N |
| LM358D | LM358D | |
| LM358N | LM358N | |
| LM363AN | | MC3450P# |
| LM363N | | MC3450P# |
| LM385BZ–1.2 | LM385BZ–1.2 | |
| LM385BZ–2.5 | LM385BZ–2.5 | |
| LM385D–1.2 | LM385D–1.2 | |
| LM385D–2.5 | LM385D–2.5 | |
| LM385M–1.2 | LM385D–1.2 | |
| LM385M–2.5 | LM385D–2.5 | |
| LM385Z–1.2 | LM385Z–1.2 | |
| LM385Z–2.5 | LM385Z–2.5 | |
| LM386N | | MC34119P |
| LM3905N | | MC1455P1 |
| LM393AN | LM393AN | |
| LM393D | LM393D | |
| LM393JG | | LM393N |
| LM393M | LM393D | |
| LM393N | LM393N | |
| LM431ACZ | TL431ACLP | |
| LM431ACM | TL431ACD | |
| LM4250CN | | MC1776CP1 |
| LM555CN | MC1455P1 | |
| LM556CN | MC3456P | |
| LM703LN | | MC1350P |
| LM723CN | MC1723CP | |
| LM741EN | | MC1741CP1 |
| LM7805CT | MC7805CT | |
| LM7812CT | MC7812CT | |
| LM7815CT | MC7815CT | |
| LM78L05ACZ | MC78L05ACP | |
| LM78L05CZ | MC78L05CP | |
| LM78L08ACZ | MC78L08ACP | |
| LM78L08CZ | MC78L08CP | |
| LM78L12ACZ | MC78L12ACP | |
| LM78L12CZ | MC78L12CP | |
| LM78L15ACZ | MC78L15ACP | |
| LM78L15CZ | MC78L15CP | |
| LM78L18ACZ | MC78L18ACP | |
| LM78L18CZ | MC78L18CP | |
| LM78L24ACZ | MC78L24ACP | |
| LM78L24CZ | MC78L24CP | |
| LM78M05CP | | MC78M05CT |
| LM78M06CP | | MC78M06CT |
| LM78M12CP | | MC78M12CT |
| LM78M15CP | | MC78M15CT |
| LM7905CT | MC7905CT | |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| LM7912CT | MC7912CT | |
| LM7915CT | MC7915CT | |
| LM79L05ACZ | MC79L05ACP | |
| LM79L12ACZ | MC79L12ACP | |
| LM79L15ACZ | MC78L15ACP | |
| LM79M05CP | | MC79M05CT |
| LM79M12CP | | MC79M12CT |
| LM79M15CP | | MC79M15CT |
| LM833D | LM833D | |
| LM833N | LM833N | |
| LM833P | LM833N | |
| LM837N | | MC33079P |
| LMC6482D | | MC33202D |
| LMC6482P | | MC33202P |
| LMC6484D | | MC33204D |
| LMC6484P | | MC33204P |
| LP2950CZ–3.0 | LP2950CZ–3.0 | |
| LP2950CZ–3.3 | LP2950CZ–3.3 | |
| LP2950CZ–5.0 | LP2950CZ–5.0 | |
| LP2950ACZ–3.0 | LP2950ACZ–3.0 | |
| LP2950ACZ–3.3 | LP2950ACZ–3.3 | |
| LP2950ACZ–5.0 | LP2950ACZ–5.0 | |
| LP2951CM | LP2951CD | |
| LP2951ACM | LP2951ACD | |
| LP2951CM–3.0 | LP2951CD–3.0 | |
| LP2951CM–3.3 | LP2951CD–3.3 | |
| LP2951ACM–3.0 | LP2951ACD–3.0 | |
| LP2951ACM–3.3 | LP2951ACD–3.3 | |
| LP2951CN | LP2951CN | |
| LP2951ACN | LP2951ACN | |
| LP2951CN–3.0 | LP2951CN–3.0 | |
| LP2951CN–3.3 | LP2951CN–3.3 | |
| LP2951ACN–3.0 | LP2951ACN–3.0 | |
| LP2951ACN–3.3 | LP2951ACN–3.3 | |
| LT1083 | | MC34268DT |
| LT1431CZ | TL431BCLP | |
| LTC699CN8 | | MC34064D–5 |
| LTC699IN8 | | MC33064D–5 |
| MAX809LCPA | | MC34064P–5 |
| MB3759 | TL494CN | |
| N5558V | MC1458P1 | |
| N5723A | | MC1723CP |
| N5741A | | MC1741CP1 |
| N5741V | MC1741CP1 | |
| N8T26AB | MC8T26AP | |
| N8T26AN | MC8T26AP | |
| N8T26B | MC8T26AP | |
| N8T26N | MC8T26AP | |
| N8T97B | MC8T97P | |
| N8T97N | MC8T97P | |
| N8T98B | MC8T98P | |
| N8T98N | MC8T98P | |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| NE550A | | MC1723CP |
| NE555D | MC1455D | |
| NE555V | MC1455P1 | |
| NE556D | NE556D | |
| NE5561N | | MC34060AP |
| NE5234D | | MC33204D |
| NE5234P | | MC33204P |
| OP–01P | | MC1436P1 |
| RC1458DN | MC1458P1 | |
| RC4136DP | | MC3403P |
| RC4136N | | MC3403P |
| RC4558DN | MC4558CP1 | |
| RC4558P | MC4558CP1 | |
| RC723DB | MC1723CP | |
| RC741DN | MC1741CP1 | |
| RE5VL47A | MC34164P–5 | |
| RH5RE30AA–T1 | MC78LC30HT1 | |
| RH5RE33AA–T1 | MC78LC33HT1 | |
| RH5RE40AA–T1 | MC78LC40HT1 | |
| RH5RE50AA–T1 | MC78LC50HT1 | |
| RN5RG30AA–TR | MC78BC30NTR | |
| RN5RG33AA–TR | MC78BC33NTR | |
| RN5RG40AA–TR | MC78BC40NTR | |
| RN5RG50AA–TR | MC78BC50NTR | |
| RH5RH301A–T1 | MC33466H–30JT1 | |
| RH5RH302B–T1 | MC33466H–30LT1 | |
| RH5RH331A–T1 | MC33466H–33JT1 | |
| RH5RH332B–T1 | MC33466H–33LT1 | |
| RH5RH501A–T1 | MC33466H–50JT1 | |
| RH5RH502B–T1 | MC33466H–50LT1 | |
| RH5RI301B–T1 | MC33463H–30KT1 | |
| RH5RI302B–T1 | MC33463H–30LT1 | |
| RH5RI331B–T1 | MC33463H–33KT1 | |
| RH5RI332B–T1 | MC33463H–33LT1 | |
| RH5RI501B–T1 | MC33463H–50KT1 | |
| RH5RI502B–T1 | MC33463H–50LT1 | |
| RH5RL30AA–T1 | MC78FC30HT1 | |
| RH5RL33AA–T1 | MC78FC33HT1 | |
| RH5RL40AA–T1 | MC78FC40HT1 | |
| RH5RL50AA–T1 | MC78FC50HT1 | |
| RH5VT09AA–T1 | MC33464H–09AT1 | |
| RH5VT20AA–T1 | MC33464H–20AT1 | |
| RH5VT27AA–T1 | MC33464H–27AT1 | |
| RH5VT30AA–T1 | MC33464H–30AT1 | |
| RH5VT45AA–T1 | MC33464H–45AT1 | |
| RH5VT09CA–T1 | MC33464H–09CT1 | |
| RH5VT20CA–T1 | MC33464H–20CT1 | |
| RH5VT27CA–T1 | MC33464H–27CT1 | |
| RH5VT30CA–T1 | MC33464H–30CT1 | |
| RH5VT45CA–T1 | MC33464H–45CT1 | |
| RN5RL30AA–TR | MC78FC30NTR | |
| RN5RL33AA–TR | MC78FC33NTR | |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| RN5RL40AA–TR | MC78FC40NTR | |
| RN5RL50AA–TR | MC78FC50NTR | |
| RN5VD09AA–TR | MC33465N–09ATR | |
| RN5VD20AA–TR | MC33465N–20ATR | |
| RN5VD27AA–TR | MC33465N–27ATR | |
| RN5VD30AA–TR | MC33465N–30ATR | |
| RN5VD45AA–TR | MC33465N–45ATR | |
| RN5VD09CA–TR | MC33465N–09CTR | |
| RN5VD20CA–TR | MC33465N–20CTR | |
| RN5VD27CA–TR | MC33465N–27CTR | |
| RN5VD30CA–TR | MC33465N–30CTR | |
| RN5VD45CA–TR | MC33465N–45CTR | |
| RN5VT09AA–TR | MC33464N–09ATR | |
| RN5VT20AA–TR | MC33464N–20ATR | |
| RN5VT27AA–T4 | MC33464N–27ATR | |
| RN5VT30AA–TR | MC33464N–30ATR | |
| RN5VT45AA–TR | MC33464N–45ATR | |
| RN5VT09CA–TR | MC33464N–09CTR | |
| RN5VT20CA–TR | MC33464N–20CTR | |
| RN5VT27CA–TR | MC33464N–27CTR | |
| RN5VT30CA–TR | MC33464N–30CTR | |
| RN5VT45CA–TR | MC33464N–45CTR | |
| S–80743AN | | MC34164P–3 |
| SA555N | MC1455BP1 | |
| SAA1042 | | SAA1042V |
| SG1458M | MC1458P1 | |
| SG1496N | MC1496P | |
| SG1596J | MC1496BP | |
| SG201AM | LM201AN | |
| SG201AN | | LM201AN |
| SG201M | LM201AN | |
| SG201N | | LM201AN |
| SG224N | LM224N | |
| SG300N | | MC1723CP |
| SG301AM | LM301AN | |
| SG301AN | | LM301AN |
| SG308AM | LM308AN | |
| SG3118AM | | LM308AN |
| SG311M | LM311N | |
| SG317P | LM317T | |
| SG317R | | LM317T |
| SG324N | LM324N | |
| SG337P | LM337T | |
| SG337R | | LM337T |
| SG3423M | | MC3423P1 |
| SG3525AN | SG3525AN | |
| SG3526N | SG3526N | |
| SG3527AN | SG3527AN | |
| SG3561 | MC34261P | |
| SG4250CM | | MC1776CP1 |
| SG555CM | MC1455P1 | |
| SG556CN | MC3456P | |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| SG723CN | MC1723CP | |
| SG741CM | MC1741CP1 | |
| SG777CN | | LM308AN |
| SG7805ACP | MC7805ACT | |
| SG7805ACR | | MC7805ACT |
| SG7805ACT | | MC7805ACT |
| SG7805CP | MC7805CT | |
| SG7806ACP | MC7806ACT | |
| SG7806ACR | | MC7806ACT |
| SG7806ACT | | MC7806ACT |
| SG7806CP | MC7806CT | |
| SG7806CR | | MC7806CT |
| SG7808ACP | MC7808ACT | |
| SG7808ACT | | MC7808ACT |
| SG7808CP | MC7808CT | |
| SG7808CR | | MC7808CT |
| SG7812ACP | MC7812ACT | |
| SG7812ACR | | MC7812ACT |
| SG7812ACT | | MC7812ACT |
| SG7812CP | MC7812CT | |
| SG7812CR | | MC7812CT |
| SG7815ACP | MC7815ACT | |
| SG7815ACR | | MC7815ACT |
| SG7815ACT | | MC7815ACT |
| SG7815CP | MC7815CT | |
| SG7815CR | | MC7815CT |
| SG7815CT | | MC7815CT |
| SG7818ACP | MC7818ACT | |
| SG7818ACR | | MC7818ACT |
| SG7818ACT | | MC7818ACT |
| SG7818CP | MC7818CT | |
| SG7818CR | | MC7818CT |
| SG7824ACP | MC7824ACT | |
| SG7824ACR | | MC7824ACT |
| SG7824ACT | | MC7824ACT |
| SG7824CP | MC7824CT | |
| SG7824CR | | MC7824CT |
| SG7905.2CP | MC7905.2CT | |
| SG7905.2CR | | MC7905.2CT |
| SG7905.2CT | | MC7905.2CT |
| SG7905ACP | MC7905ACT | |
| SG7905ACR | | MC7905ACT |
| SG7905ACT | | MC7905ACT |
| SG7905CP | MC7905CT | |
| SG7905CR | | MC7905CT |
| SG7905CT | | MC7905CT |
| SG7908CP | MC7908CT | |
| SG7908CR | | MC7908CT |
| SG7908CT | | MC7908CT |
| SG7912ACP | MC7912ACT | |
| SG7912ACR | | MC7912ACT |
| SG7912ACT | | MC7912ACT |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| SG7912CP | MC7912CT | |
| SG7912CR | | MC7912CT |
| SG7912CT | | MC7912CT |
| SG79015ACP | MC7915ACT | |
| SG7915ACR | | MC7915ACT |
| SG7915ACT | | MC7915ACT |
| SG7915CP | MC7915CT | |
| SG7915CR | | MC7915CT |
| SG7915CT | | MC7915CT |
| SG7918CP | MC7918CT | |
| SN75LBC086 | | MC34055DW |
| SN75121N | | MC3481/5P# |
| SN75126N | | MC3481/5P# |
| SN75150N | | MC1488P |
| SN75154N | | MC1489P |
| SN75174N | MC75174BP | |
| SN75175N | SN75175N | |
| SN75188N | MC1488P | |
| SN75189AN | MC1489AP | |
| SN75189N | MC1489P | |
| SN75468N | MC1413P | |
| SN76591P | MC1391P | |
| SN76600P | MC1350P | |
| SSS201AP | LM201AN | |
| SSS301AP | LM301AN | |
| TA7504P | MC1741CP1 | |
| TA7506P | LM301AN | |
| TA75071P | | MC34001P |
| TA75072P | | MC34002P |
| TA75074F | | MC34004P |
| TA75339F | LM339D | |
| TA75339P | LM339N | |
| TA75358CF | LM358D | |
| TA75358CP | LM358N | |
| TA75393F | LM393D | |
| TA75393P | LM393N | |
| TA75458F | MC1458D | |
| TA75458P | MC1458CP1 | |
| TA75558P | MC4558CP1 | |
| TA7555F | MC1455D | |
| TA7555P | MC1455P1 | |
| TA75902F | LM324D | |
| TA76494P | | TL494IN |
| TA78005AP | MC7805CT | |
| TA78006AP | MC7806CT | |
| TA78008AP | MC7808CT | |
| TA78012AP | MC7812CT | |
| TA78015AP | MC7815CT | |
| TA78018AP | MC7818CT | |
| TA78024AP | MC7824CT | |
| TA78L005AP | | MC78L05ACP |
| TA78L005P | | MC78L05CP |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| TA78L008AP | | MC78L08ACP |
| TA78L008P | | MC78L08CP |
| TA78L012AP | | MC78L12ACP |
| TA78L012P | | MC78L12CP |
| TA78L015AP | | MC78L15ACP |
| TA78L015P | | MC78L15CP |
| TA78L018AP | | MC78L18ACP |
| TA78L018P | | MC78L18CP |
| TA78L024AP | | MC78L24ACP |
| TA78L024P | | MC78L24CP |
| TA78M05P | MC78M05CT | |
| TA78M06P | MC78M06CT | |
| TA78M08P | MC78M08CT | |
| TA78M12P | MC78M12CT | |
| TA78M18P | MC78M18CT | |
| TA78M20P | MC78M20CT | |
| TA78M24P | MC78M24CT | |
| TA79005P | MC7905CT | |
| TA79006P | MC7906CT | |
| TA79008P | MC7908CT | |
| TA79012P | MC7912CT | |
| TA79015P | MC7915CT | |
| TA79018P | MC7918CT | |
| TA79024P | MC7924CT | |
| TA79L005P | | MC79L05CP |
| TA79L012P | | MC79L12P |
| TA79L015P | | MC79L15P |
| TA79L018P | | MC79L18P |
| TA79L024P | | MC79L24P |
| TB920 | | MC1391P |
| TBA920S | | MC1391P |
| TCF5600 | TCF5600 | |
| TD62003P/AP | MC1413P | |
| TD62479P | MC1374P | |
| TDA1085C | TDA1085C | |
| TDA1085 | | TDA1085C |
| TDA1185A | TDA1185A# | |
| TDA4817 | | MC34261P |
| TDC1018 | | MC10324P |
| TDC1048 | | MC10319P |
| TK115 | MC33264 | |
| TL022CP | | LM358N |
| TL044CJ | | LM324N |
| TL062ACP | TL062ACP | |
| TL062CD | TL062CD | |
| TL062CP | TL062CP | |
| TL062VP | TL062VP | |
| TL064ACD | TL064ACD | |
| TL064ACN | TL064ACN | |
| TL064CD | TL064CD | |
| TL064CN | TL064CN | |
| TL064VN | TL064VN | |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| TL071ACD | TL071ACD | |
| TL071ACP | TL071ACP | |
| TL071CD | TL071CD | |
| TL071CP | TL071CP | |
| TL072ACD | TL072ACD | |
| TL072ACP | TL072ACP | |
| TL072CD | TL072CD | |
| TL072CP | TL072CP | |
| TL074ACN | TL074ACN | |
| TL074CN | TL074CN | |
| TL081ACD | TL081ACD | |
| TL081ACP | TL081ACP | |
| TL081CD | TL081CD | |
| TL081CP | TL081CP | |
| TL082ACP | TL082ACP | |
| TL082CD | TL082CD | |
| TL082CP | TL082CP | |
| TL084ACN | TL084ACN | |
| TL084CN | TL084CN | |
| TL431CD | TL431CD | |
| TL431CLP | TL431CLP | |
| TL431CP | TL431CP | |
| TL431ILP | TL431ILP | |
| TL431IP | TL431IP | |
| TL494CN | TL494CN | |
| TL494IN | TL494IN | |
| TL497CN | | MC34063AP1 |
| TL594CN | TL594CN | |
| TL594IN | TL594IN | |
| TL780–05CKC | TL780–05CKC | |
| TL780–12CKC | TL780–12CKC | |
| TL780–15CKC | TL780–15CKC | |
| TL7805ACKC | MC7805ACT | |
| TLC2272D | | MC33202D |
| TLC2272P | | MC33202P |
| TLC2274D | | MC33204D |
| TLC2274P | | MC33204P |
| µA1391PC | MC1391P | |
| µA1458CP | MC1458CP1 | |
| µA1458CTC | MC1458CP1 | |
| µA1458P | MC1458P1 | |
| µA1458TC | MC1458P1 | |
| µA2240PC | | MC1455P1 |
| µA301AT | LM301AN | |
| µA3026HM | | CA3054 |
| µA3045 | | MC3346P |
| µA3046DC | MC3346P | |
| µA3054DC | CA3054 | |
| µA311T | LM311N | |
| µA317UC | LM317T | |
| µA3303P | MC3303P | |
| µA3403P | MC3403P | |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| µA4136PC | | MC4741CP |
| µA431AWC | TL431CP | |
| µA4558TC | MC4558CP1 | |
| µA494PC | TL494CN | |
| µA555TC | MC1455P1 | |
| µA556PC | MC3456P | |
| µA723CN | MC1723CP | |
| µA723PC | MC1723CP | |
| µA741CP | MC1741CP1 | |
| µA742DC | | CA3059 |
| µA757DC | | MC1350P |
| µA757DM | | MC1350P |
| µA775PC | LM339N | |
| µA776TC | MC1776CP1 | |
| µA7805CKC | MC7805CT | |
| µA7805UC | MC7805CT | |
| µA7805UV | MC7805BT | |
| µA7806CKC | MC7806CT | |
| µA7806UC | MC7806CT | |
| µA7806UV | MC7806BT | |
| µA7808CKC | MC7808CT | |
| µA7808UC | MC7808CT | |
| µA7808UV | MC7808BT | |
| µA7812CKC | MC7812CT | |
| µA7812UC | MC7812CT | |
| µA7812UV | MC7812BT | |
| µA7815CKC | MC7815CT | |
| µA7815UC | MC7815CT | |
| µA7815UV | MC7815BT | |
| µA7818CKC | MC7818CT | |
| µA7818UC | MC7818CT | |
| µA7818UV | MC7818BT | |
| µA7824CKC | MC7824CT | |
| µA7824UC | MC7824CT | |
| µA7824UV | MC7824BT | |
| µA78GU1C | | LM317T |
| µA78GUC | | LM317T |
| µA78L05ACLP | MC78L05ACP | |
| µA78L05AWC | | MC78L05ACP |
| µA78L05CLP | MC78L05CP | |
| µA78L05WC | | MC78L05CP |
| µA78L08ACLP | MC78L08ACP | |
| µA78L08AWC | | MC78L08ACP |
| µA78L08CLP | MC78L08CP | |
| µA78L12ACLP | MC78L12ACP | |
| µA78L12AWC | | MC78L12ACP |
| µA78L12CLP | MC78L12CP | |
| µA78L12WC | | MC78L12CP |
| µA78L15ACLP | MC78L15ACP | |
| µA78L15AWC | | MC78L15ACP |
| µA78L15CLP | MC78L15CP | |
| µA78L15WC | | MC78L15CP |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| µA78L18AWC | | MC78L18ACP |
| µA78L24AWC | MC78L24ACP | |
| µA78M05CKC | MC78M05CT | |
| µA78M05CKD | | MC78M05CT |
| µA78M05UC | MC78M05CT | |
| µA78M06CKC | MC78M06CT | |
| µA78M06CKD | | MC78M06CT |
| µA78M06UC | MC78M06CT | |
| µA78M08CKC | MC78M08CT | |
| µA78M08CKD | | MC78M08CT |
| µA78M08UC | MC78M08CT | |
| µA78M12CKC | MC78M12CT | |
| µA78M12CKD | | MC78M12CT |
| µA78M12UC | MC78M12CT | |
| µA78M15CKC | MC78M15CT | |
| µA78M15CKD | | MC78M15CT |
| µA78M15UC | MC78M15CT | |
| µA78M18UC | MC78M18CT | |
| µA78M20CKC | MC78M20CT | |
| µA78M20CKD | | MC78M20CT |
| µA78M20UC | MC78M20CT | |
| µA78M24CKC | MC78M24CT | |
| µA78M24CKD | | MC78M24CT |
| µA78M24UC | MC78M24CT | |
| µA78MGT2C | | LM317T |
| µA78MGU1C | | LM317T |
| µA78MGUC | | LM317MT |
| µA78S40PC | µA78S40PC | |
| µA78S40PV | µA78S40PV | |
| µA7905.2CKC | MC7905.2CT | |
| µA7905CKC | MC7905CT | |
| µA7905UC | MC7905CT | |
| µA7906CKC | MC7906CT | |
| µA7906UC | MC7906CT | |
| µA7908CKC | MC7908CT | |
| µA7912CKC | MC7912CT | |
| µA7912UC | MC7912CT | |
| µA7915CKC | MC7915CT | |
| µA7915UC | MC7915CT | |
| µA7918CKC | MC7918CT | |
| µA7918UC | MC7918CT | |
| µA7924CKC | MC7924CT | |
| µA7924UC | MC7924CT | |
| µA798TC | MC3458P1 | |
| µA79L05AWC | MC79L05ACP | |
| µA79L05WC | MC79L05CP | |
| µA79L12AWC | MC79L12ACP | |
| µA79L12WC | MC79L12CP | |
| µA79L15AWC | MC79L15ACP | |
| µA79L15WC | MC79L15CP | |
| µA79M05AUC | MC79M05CT | |
| µA79M05CKC | MC79M05CT | |

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| µA79M06AUC | | MC79M06CT |
| µA79M06CKC | | MC79M06CT |
| µA79M06UC | | MC79M06CT |
| µA79M08AUC | | MC79M08CT |
| µA79M08CKC | | MC79M08CT |
| µA79M08UC | | MC79M08CT |
| µA79M12AUC | MC79M12CT | |
| µA79M12CKC | MC79M12CT | |
| µA79M18AUC | | MC79M18CT |
| µA79M18UC | | MC79M18CT |
| µA79M24AUC | | MC79M24CT |
| µA79M24CKC | | MC79M24CT |
| µA79M24UC | | MC79M24CT |
| µA9636ATC | MC3488AP1 | |
| UAA1016B | UAA1016B | |
| UC2823DW | | MC33023DW |
| UC2823N | | MC33023P |
| UC2823Q | | MC33023FN |
| UC2825DW | | MC33025DW |
| UC2825N | | MC33025P |
| UC2825Q | | MC33025FN |
| UC2842AD | UC2842AD | |
| UC2842AN | UC2842AN | |
| UC2842BD | UC2842BD | |
| UC2842BN | UC2842BN | |
| UC2842D | UC2842AD | |
| UC2842N | UC2842AN | |
| UC2843AD | UC2843AD | |
| UC2843AN | UC2843AN | |
| UC2843BD | UC2843BD | |
| UC2843BN | UC2843BN | |
| UC2843D | UC2843AD | |
| UC2843N | UC2843AN | |
| UC2844BD | UC2844BD | |
| UC2844BN | UC2844BN | |
| UC2844D | UC2844D | |
| UC2844N | UC2844N | |
| UC2845BD | UC2845BD | |
| UC2845BN | UC2845BN | |
| UC2845D | UC2845D | |
| UC2845N | UC2845N | |
| UC317T | LM317T | |
| UC337T | LM337T | |
| UC3525AN | SG3525AN | |
| UC3526N | SG3526N | |
| UC3527AN | SG3527AN | |
| UC3823DW | | MC34023DW |
| UC3823N | | MC34023P |
| UC3823Q | | MC34023FN |
| UC3825DW | | MC34025DW |
| UC3825N | | MC34025P |
| UC3825Q | | MC34025FN |

# = Not recommended for new designs.

## Cross References (continued)

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| UC3842AD | UC3842AD | |
| UC3842AN | UC3842AN | |
| UC3842BD | UC3842BD | |
| UC3842BN | UC3842BN | |
| UC3842D | UC3842AD | |
| UC3842N | UC3842AN | |
| UC3843AD | UC3843AD | |
| UC3843AN | UC3843AN | |
| UC3843BD | UC3843BD | |
| UC3843BN | UC3843BN | |
| UC3843D | UC3843AD | |
| UC3843N | UC3843AN | |
| UC3844BD | UC3844BD | |
| UC3844BN | UC3844BN | |
| UC3844D | UC3844D | |
| UC3844N | UC3844N | |
| UC3845BD | UC3845BD | |
| UC3845BN | UC3845BN | |
| UC3845D | UC3845D | |

# = Not recommended for new designs.

| Industry Part Number | Motorola Nearest Replacement | Motorola Similar Replacement |
|---|---|---|
| UC3845N | UC3845N | |
| UC494ACN | | TL594CN |
| UC494CN | | TL494CN |
| UCN5816A | MC34142FN | |
| ULN2003A | MC1413 | |
| ULN2004A | MC1416 | |
| ULN2068BB | ULN2068B# | |
| ULN2068NE | ULN2068B# | |
| ULN2151H | MC1741CP1 | |
| ULN2151M | | MC1741CP1 |
| ULN2803A | ULN2803A | |
| ULN2804A | ULN2804A | |
| ULN8126A | SG3526N | |
| ULS2151M | | MC1741CP1 |
| ULX8161M | | MC34060AP |
| UPD6950C | | MC10319P |
| UVC3101 | | MC10319P |
| XR082CP | TL082CP | |
| XR084CP | TL084CN | |

# Voltage References

5

## In Brief . . .

Motorola's line of precision voltage references is designed for applications requiring high initial accuracy, low temperature drift, and long term stability. Initial accuracies of ±1.0%, and ±2.0% mean production line adjustments can be eliminated. Temperature coefficients of 25 ppm/°C max (typically 10 ppm/°C) provide excellent stability. Uses for the references include D/A converters, A/D converters, precision power supplies, voltmeter systems, temperature monitors, and many others.


| | Page |
|---|---|
| Precision Low Voltage References | 5–2 |
| Package Overview | 5–2 |
| Device Listing | 5–3 |

# Precision Low Voltage References

A family of precision low voltage bandgap reference devices designed for applications requiring low temperature drift.

### 1Precision Low Voltage References

| $V_{out}$ (V) Typ | $I_O$ (mA) Max | $V_{out}/T$ ppm/°C Max | Device | | $Reg_{line}$ (mV) Max | $Reg_{load}$ (mV) Max | Package |
|---|---|---|---|---|---|---|---|
| | | | 0° to +70°C | –40° to +85°C | | | |
| 1.235 ± 12 mV<br>1.235 ± 25 mV | 20 | 80 Typ | LM385BZ–1.2<br>LM385Z–1.2 | LM285Z–1.2 | (Note 1) | 1.0<br>(Note 2) | Z, D |
| 2.5 ± 38 mV<br>2.5 ± 75 mV | | | LM385BZ–2.5<br>LM385Z–2.5 | LM285Z–2.5 | | 2.0<br>(Note 3) | |
| 2.5 ± 25 mV | 10 | 25 | MC1403A | – | 3.0/4.5<br>(Note 4) | 10<br>(Note 5) | D |
| | | 40 | MC1403 | | | | |
| 5.0 ± 50 mV | | 40 | MC1404P5 | – | 6.0<br>(Note 6) | | P |
| 6.25 ± 60 mV | | 40 | MC1404P6 | – | | | |
| 10 ± 100 mV | | 40 | MC1404P10 | – | | | |
| 2.5 to 37 | 100 | 50 Typ | TL431C, AC, BC | TL431I, AI, BI | Shunt Reference Dynamic Impedance (z) ≤ 0.5 Ω | | LP, P, D, DM |

Notes: 1. Micropower Reference Diode Dynamic Impedance (z) ≤ 1.0 Ω at $I_R$ = 100 μA.
2. 10 μA ≤ $I_R$ ≤ 1.0 mA.
3. 20 μA ≤ $I_R$ ≤ 1.0 mA.
4. 4.5 V ≤ $V_{in}$ ≤ 15 V/15 V ≤ $V_{in}$ ≤ 40 V.
5. 0 mA ≤ $I_L$ ≤ 10 mA.
6. ($V_{out}$ + 2.5 V) ≤ $V_{in}$ ≤ 40 V.

# Voltage References Package Overview

**CASE 29**
**LP, Z SUFFIX**

**CASE 626**
**P SUFFIX**

**CASE 751**
**D SUFFIX**

**CASE 846A**
**DM SUFFIX**

# Device Listing

## Voltage References


| Device | Function | Page |
|---|---|---|
| **LM285, LM385, B** | Micropower Voltage Reference Diodes | 5–4 |
| **MC1403, B** | Low Voltage Reference | 5–9 |
| **MC1404** | Voltage Reference Family | 5–13 |
| **TL431, A, B Series** | Programmable Precision References | 5–18 |


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MOTOROLA

# LM285
# LM385, B

## Micropower Voltage Reference Diodes

**MICROPOWER VOLTAGE REFERENCE DIODES**

**SEMICONDUCTOR TECHNICAL DATA**

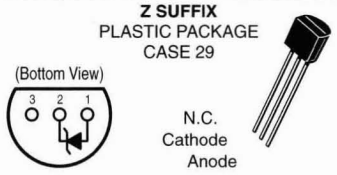
The LM285/LM385 series are micropower two–terminal bandgap voltage regulator diodes. Designed to operate over a wide current range of 10 μA to 20 mA, these devices feature exceptionally low dynamic impedance, low noise and stable operation over time and temperature. Tight voltage tolerances are achieved by on–chip trimming. The large dynamic operating range enables these devices to be used in applications with widely varying supplies with excellent regulation. Extremely low operating current make these devices ideal for micropower circuitry like portable instrumentation, regulators and other analog circuitry where extended battery life is required.

The LM285/LM385 series are packaged in a low cost TO–226AA plastic case and are available in two voltage versions of 1.235 and 2.500 V as denoted by the device suffix (see Ordering Information table). The LM285 is specified over a –40°C to +85°C temperature range while the LM385 is rated from 0°C to +70°C.

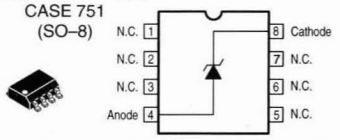
The LM385 is also available in a surface mount plastic package in voltages of 1.235 and 2.500 V.

- Operating Current from 10 μA to 20 mA
- 1.0%, 1.5%, 2.0% and 3.0% Initial Tolerance Grades
- Low Temperature Coefficient
- 1.0 Ω Dynamic Impedance
- Surface Mount Package Available

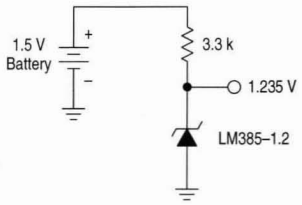
**Z SUFFIX**
PLASTIC PACKAGE
CASE 29



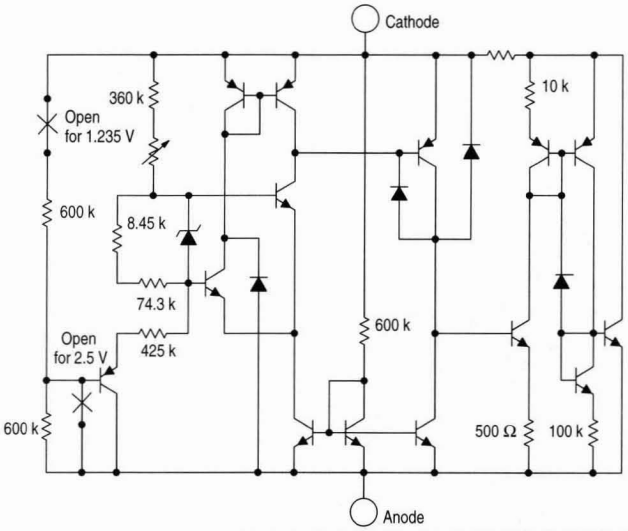

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)




**Standard Application**




**Representative Schematic Diagram**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Reverse Break–down Voltage | Tolerance |
|---|---|---|---|
| LM285D–1.2<br>LM285Z–1.2 | $T_A$ = –40° to +85°C | 1.235 V | ±1.0% |
| LM285D–2.5<br>LM285Z–2.5 | | 2.500 V | ±1.5% |
| LM385BD–1.2<br>LM385BZ–1.2 | $T_A$ = 0° to +70°C | 1.235 V | ±1.0% |
| LM385D–1.2<br>LM385Z–1.2 | | 1.235 V | ±2.0% |
| LM385BD–2.5<br>LM385BZ–2.5 | | 2.500 V | ±1.5% |
| LM385D–2.5<br>LM385Z–2.5 | | 2.500 V | ±3.0% |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Reverse Current | $I_R$ | 30 | mA |
| Forward Current | $I_F$ | 10 | mA |
| Operating Ambient Temperature Range<br>LM285<br>LM385 | $T_A$ | <br>– 40 to + 85<br>0 to +70 | °C |
| Operating Junction Temperature | $T_J$ | + 150 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted)

| Characteristic | Symbol | LM285–1.2 | | | LM385–1.2/LM385B–1.2 | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | |
| Reverse Breakdown Voltage ($I_{Rmin} \leq I_R \leq$ 20 mA) | $V_{(BR)R}$ | | | | | | | V |
| LM285–1.2/LM385B–1.2 | | 1.223 | 1.235 | 1.247 | 1.223 | 1.235 | 1.247 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | 1.200 | – | 1.270 | 1.210 | – | 1.260 | |
| LM385–1.2 | | – | – | – | 1.205 | 1.235 | 1.260 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | – | 1.192 | – | 1.273 | |
| Minimum Operating Current | $I_{Rmin}$ | | | | | | | µA |
| $T_A$ = 25°C | | – | 8.0 | 10 | – | 8.0 | 15 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 20 | – | – | 20 | |
| Reverse Breakdown Voltage Change with Current | $\Delta V_{(BR)R}$ | | | | | | | mV |
| $I_{Rmin} \leq I_R \leq$ 1.0 mA, $T_A$ = +25°C | | – | – | 1.0 | – | – | 1.0 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 1.5 | – | – | 1.5 | |
| 1.0 mA $\leq I_R \leq$ 20 mA, $T_A$ = +25°C | | – | – | 10 | – | – | 20 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 20 | – | – | 25 | |
| Reverse Dynamic Impedance<br>$I_R$ = 100 µA, $T_A$ = +25°C | Z | | 0.6 | – | – | 0.6 | – | W |
| Average Temperature Coefficient<br>10 µA $\leq I_R \leq$ 20 mA, $T_A = T_{low}$ to $T_{high}$ (Note 1) | $\Delta V_{(BR)}/\Delta T$ | – | 80 | – | – | 80 | – | ppm/°C |
| Wideband Noise (RMS)<br>$I_R$ = 100 µA, 10 Hz $\leq$ f $\leq$ 10 kHz | n | – | 60 | – | – | 60 | – | µV |
| Long Term Stability<br>$I_R$ = 100 µA, $T_A$ = +25°C ± 0.1°C | S | – | 20 | – | – | 20 | – | ppm/<br>kHR |

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**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted)

| Characteristic | Symbol | LM285–2.5 | | | LM385–2.5/LM385B–2.5 | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | |
| Reverse Breakdown Voltage ($I_{Rmin} \leq I_R \leq 20$ mA) | $V_{(BR)R}$ | | | | | | | V |
| LM285–2.5/LM385B–2.5 | | 2.462 | 2.5 | 2.538 | 2.462 | 2.5 | 2.538 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | 2.415 | – | 2.585 | 2.436 | – | 2.564 | |
| LM385–2.5 | | – | – | – | 2.425 | 2.5 | 2.575 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | – | 2.400 | – | 2.600 | |
| Minimum Operating Current | $I_{Rmin}$ | | | | | | | μA |
| $T_A$ = 25°C | | – | 13 | 20 | – | 13 | 20 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 30 | – | – | 30 | |
| Reverse Breakdown Voltage Change with Current | $\Delta V_{(BR)R}$ | | | | | | | mV |
| $I_{Rmin} \leq I_R \leq 1.0$ mA, $T_A$ = +25°C | | – | – | 1.0 | – | – | 2.0 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 1.5 | – | – | 2.5 | |
| 1.0 mA $\leq I_R \leq$ 20 mA, $T_A$ = +25°C | | – | – | 10 | – | – | 20 | |
| $T_A = T_{low}$ to $T_{high}$ (Note 1) | | – | – | 20 | – | – | 25 | |
| Reverse Dynamic Impedance | Z | | 0.6 | – | – | 0.6 | – | W |
| $I_R$ = 100 μA, $T_A$ = +25°C | | | | | | | | |
| Average Temperature Coefficient | $\Delta V_{(BR)}/\Delta T$ | – | 80 | – | – | 80 | – | ppm/°C |
| 20 μA $\leq I_R \leq$ 20 mA, $T_A = T_{low}$ to $T_{high}$ (Note 1) | | | | | | | | |
| Wideband Noise (RMS) | n | – | 120 | – | – | 120 | – | μV |
| $I_R$ = 100 μA, 10 Hz $\leq$ f $\leq$ 10 kHz | | | | | | | | |
| Long Term Stability | S | – | 20 | – | – | 20 | – | ppm/ kHR |
| $I_R$ = 100 μA, $T_A$ = +25°C ± 0.1°C | | | | | | | | |

**NOTES:** 1. $T_{low}$ = – 40°C for LM285–1.2, LM285–2.5
= 0°C for LM385–1.2, LM385B–1.2, LM385–2.5, LM385B–2.5
$T_{high}$ = +85°C for LM285–1.2, LM285–2.5
= +70°C for LM385–1.2, LM385B–1.2, LM385–2.5, LM385B–2.5

## TYPICAL PERFORMANCE CURVES FOR LM285–1.2/385–1.2/385B–1.2

**Figure 1. Reverse Characteristics**

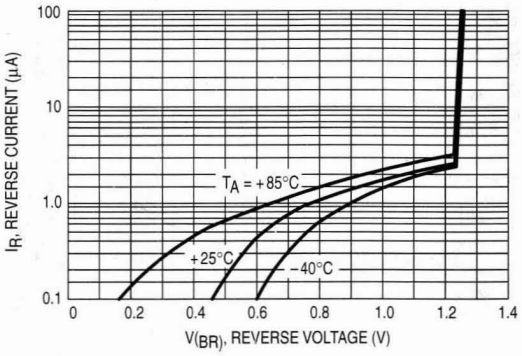


**Figure 2. Reverse Characteristics**

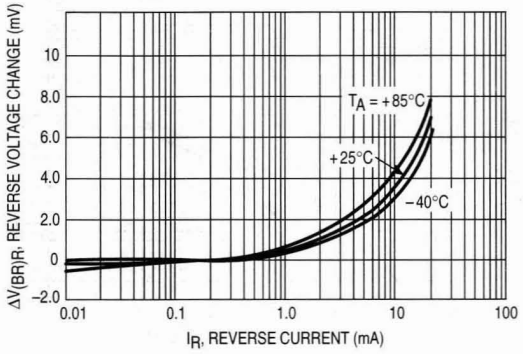


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**Figure 3. Forward Characteristics**

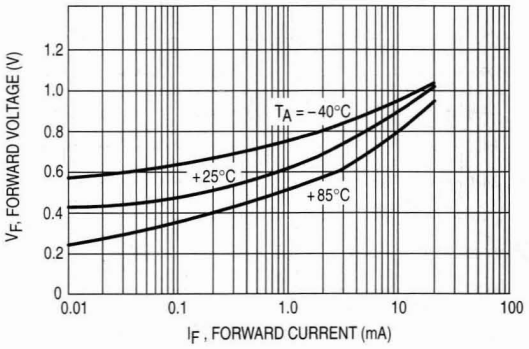



**Figure 4. Temperature Drift**

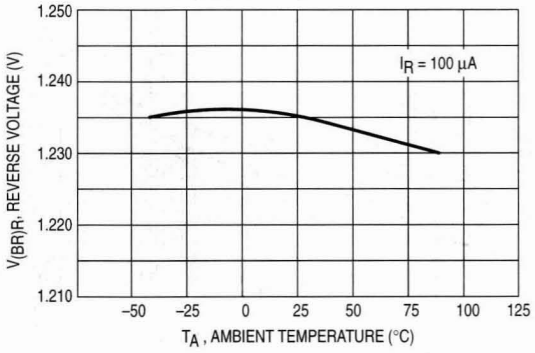



**Figure 5. Noise Voltage**

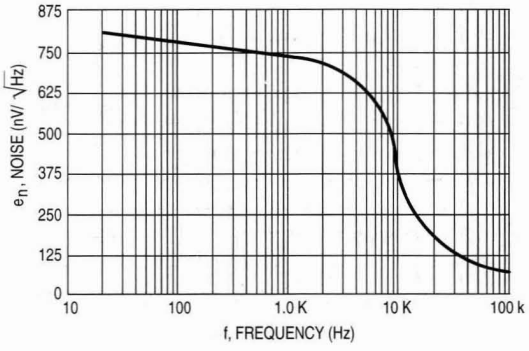
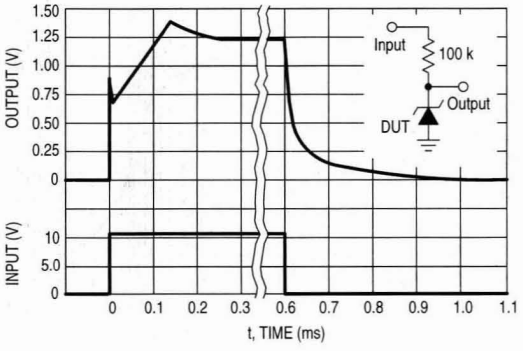



**Figure 6. Response Time**



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## TYPICAL PERFORMANCE CURVES FOR LM285–2.5/385–2.5/385B–2.5

**Figure 7. Reverse Characteristics**

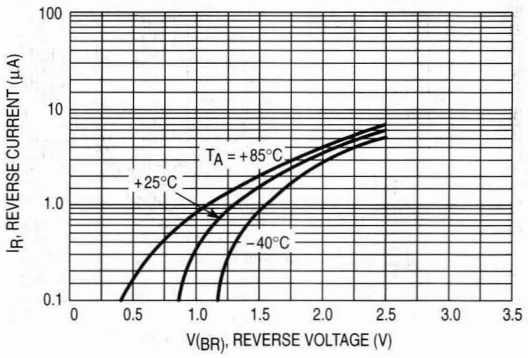



**Figure 8. Reverse Characteristics**

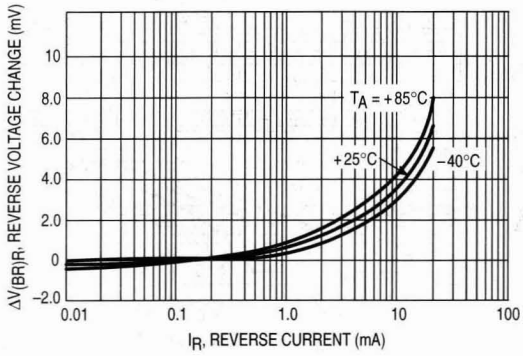



**Figure 9. Forward Characteristics**

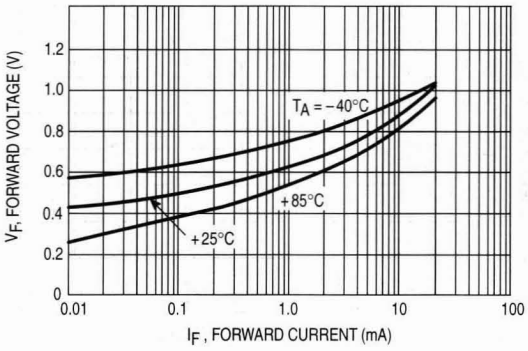



**Figure 10. Temperature Drift**

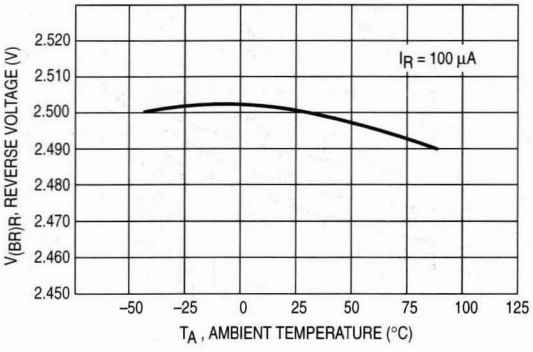



**Figure 11. Noise Voltage**

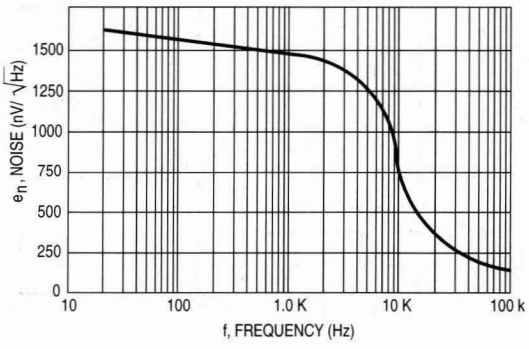
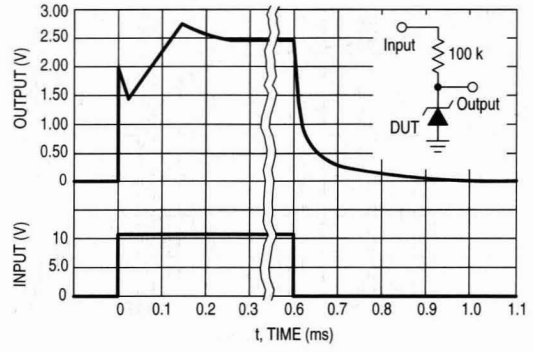



**Figure 12. Response Time**



MOTOROLA

# MC1403, B

## Low Voltage Reference

A precision band–gap voltage reference designed for critical instrumentation and D/A converter applications. This unit is designed to work with D/A converters, up to 12 bits in accuracy, or as a reference for power supply applications.

- Output Voltage: 2.5 V ±25 mV
- Input Voltage Range: 4.5 V to 40 V
- Quiescent Current: 1.2 mA Typical
- Output Current: 10 mA
- Temperature Coefficient: 10 ppm/°C Typical
- Guaranteed Temperature Drift Specification
- Equivalent to AD580
- Standard 8–Pin DIP, and 8–Pin SOIC Package

**Typical Applications**

- Voltage Reference for 8 to 12 Bit D/A Converters
- Low $T_C$ Zener Replacement
- High Stability Current Reference
- Voltmeter System Reference

**PRECISION LOW VOLTAGE REFERENCE**

**SEMICONDUCTOR TECHNICAL DATA**

**P1 SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

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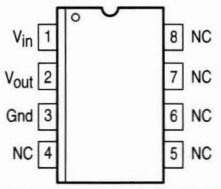
**PIN CONNECTIONS**



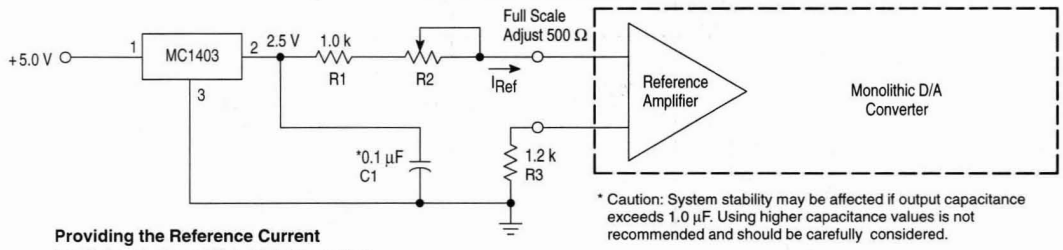

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Input Voltage | $V_I$ | 40 | V |
| Storage Temperature | $T_{stg}$ | −65 to 150 | °C |
| Junction Temperature | $T_J$ | +175 | °C |
| Operating Ambient Temperature Range<br>MC1403B<br>MC1403 | $T_A$ | <br>−40 to +85<br>0 to +70 | <br>°C<br>°C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1403D | $T_A$ = 0° to +70°C | SO–8 |
| MC1403P1 | | Plastic DIP |
| MC1403BD | $T_A$ = −40° to +85°C | SO–8 |
| MC1403BP1 | | Plastic DIP |

**Figure 1. A Reference for Monolithic D/A Converters**




* Caution: System stability may be affected if output capacitance exceeds 1.0 μF. Using higher capacitance values is not recommended and should be carefully considered.

**Providing the Reference Current for Motorola Monolithic D/A Converters**

The MC1403 makes an ideal reference for many monolithic D/A converters, requiring a stable current reference of nominally 2.0 mA. This can be easily obtained from the MC1403 with the addition of a series resistor, R1. A variable resistor, R2, is recommended to provide means for full–scale adjust on the D/A converter.

The resistor R3 improves temperature performance by matching the impedance on both inputs of the D/A reference amplifier. The capacitor decouples any noise present on the reference line. It is essential if the D/A converter is located any appreciable distance from the reference.

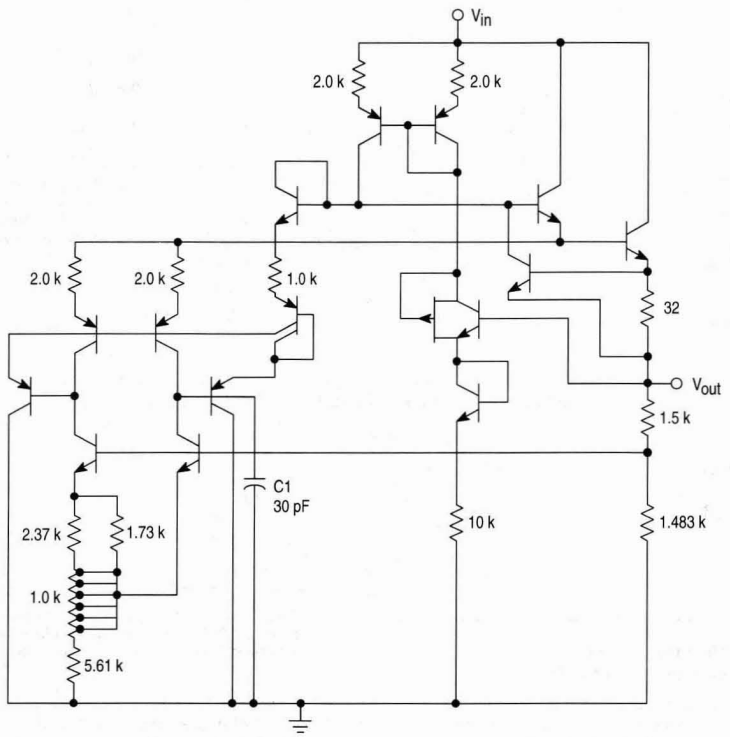
A single MC1403 reference can provide the required current input for up to five of the monolithic D/A converters.

**ELECTRICAL CHARACTERISTICS** ($V_{in}$ = 15 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Voltage<br>($I_O$ = 0 mA) | $V_{out}$ | 2.475 | 2.5 | 2.525 | V |
| Temperature Coefficient of Output Voltage*<br>MC1403 | $\Delta V_O/\Delta T$ | – | 10 | 40 | ppm/°C |
| Output Voltage Change*<br>(Over specified temperature range)<br>MC1403 0 to +70°C<br>MC1403B −40 to +85°C | $\Delta V_O$ | <br><br>–<br>– | <br><br>–<br>– | <br><br>7.0<br>12.5 | mV |
| Line Regulation ($I_O$ = 0 mA)<br>(15 V ≤ $V_I$ ≤ 40 V)<br>(4.5 V ≤ $V_I$ ≤ 15 V) | $Reg_{line}$ | <br>–<br>– | <br>1.2<br>0.6 | <br>4.5<br>3.0 | mV |
| Load Regulation<br>(0 mA < $I_O$ < 10 mA) | $Reg_{load}$ | – | – | 10 | mV |
| Quiescent Current<br>($I_O$ = 0 mA) | $I_Q$ | – | 1.2 | 1.5 | mA |

* This test is not applicable to the MC1403D or MC1403BD surface mount devices.

**Figure 2. MC1403, B Schematic**




This device contains 15 active transistors.

**Figure 3. Typical Change in $V_{out}$ versus $V_{in}$**

(Normalized to $V_{in}$ = 15 V @ $T_C$ = 25°C)

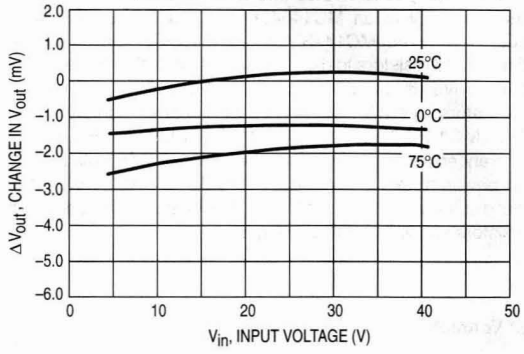
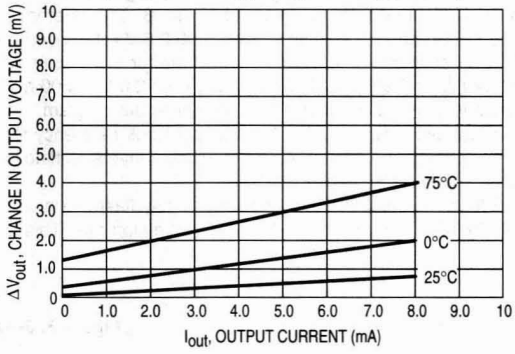



**Figure 4. Change in Output Voltage versus Load Current**

(Normalized to $V_{out}$ @ $V_{in}$ = 15 V, $I_{out}$ = 0 mA)




5

**Figure 5. Quiescent Current versus Temperature**

($V_{in}$ = 15 V, $I_{out}$ = 0 mA)

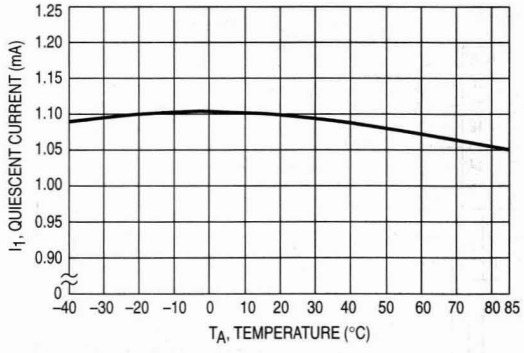



**Figure 6. Change in $V_{out}$ versus Temperature**

(Normalized to $V_{out}$ @ $V_{in}$ = 15 V)

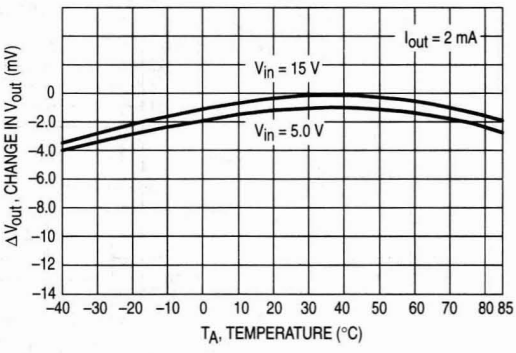
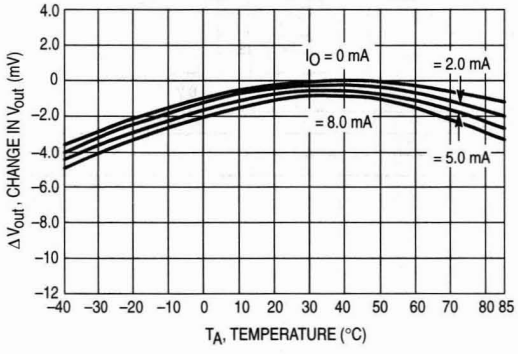



**Figure 7. Change in $V_{out}$ versus Temperature**

(Normalized to $T_A$ = 25°C, $V_{in}$ = 15 V, $I_{out}$ = 0 mA)



### 3–1/2–Digit Voltmeter – Common Anode Displays, Flashing Overrange

An example of a 3–1/2–digit voltmeter using the MC14433 is shown in the circuit diagram of Figure 8. The reference voltage for the system uses an MC1403 2.5 V reference IC. The full scale potentiometer can calibrate for a full scale of 199.9 mV or 1.999 V. When switching from 2.0 V to 200 mV operation, $R_I$ is also changed, as shown on the diagram.

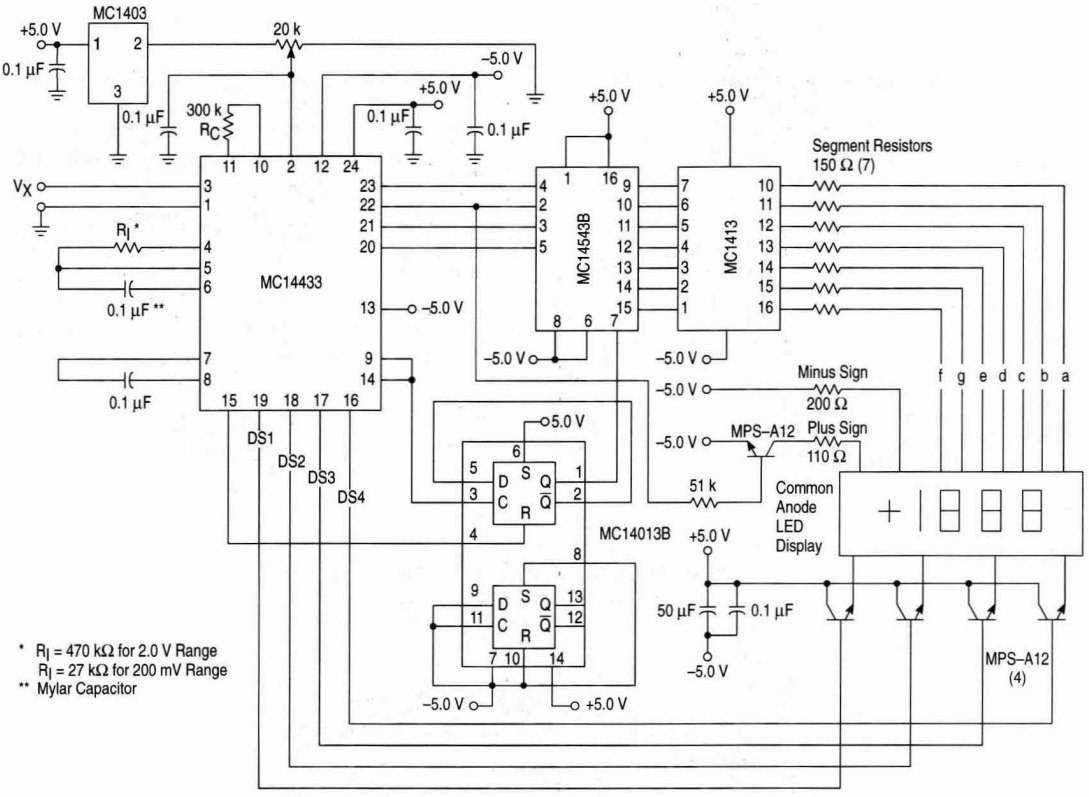
When using $R_C$ equal to 300 kΩ, the clock frequency for the system is about 66 kHz. The resulting conversion time is approximately 250 ms.

When the input is overrange, the display flashes on and off. The flashing rate is one–half the conversion rate. This is done by dividing the EOC pulse rate by 2 with 1/2 MC14013B flip–flop and blanking the display using the blanking input of the MC14543B.

The display uses an LED display with common anode digit lines driven with an MC14543B decoder and an MC1413 LED driver. The MC1413 contains 7 Darlington transistor drivers and resistors to drive the segments of the display. The digit drive is provided by four MPS–A12 Darlington transistors operating in an emitter–follower configuration. The MC14543B, MC14013B and LED displays are referenced to $V_{EE}$ via Pin 13 of the MC14433. This places the full power supply voltage across the display. The current for the display may be adjusted by the value of the segment resistors shown as 150 Ω in Figure 8.

5

**Figure 8. 3–1/2–Digit Voltmeter**



MOTOROLA

# MC1404

## Voltage Reference Family

The MC1404 of ICs is a family of temperature–compensated voltage references for precision data conversion applications, such as A/D, D/A, V/F, and F/V. Advances in laser–trimming and ion–implanted devices, as well as monolithic fabrication techniques, make these devices stable and accurate to 12 bits over both military and commercial temperature ranges. In addition to excellent temperature stability, these parts offer excellent long–term stability and low noise.

- Output Voltages: Standard, 5.0 V, 6.25 V, 10 V
- Trimmable Output: > ± 6%
- Wide Input Voltage Range: $V_{ref}$ + 2.5 V to 40 V
- Low Quiescent Current: 1.25 mA Typical
- Temperature Coefficient: 10 ppm/°C Typical
- Low Output Noise: 12 μV p–p Typical
- Excellent Ripple Rejection: > 80 dB Typical

**Typical Applications**

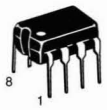
- Voltage Reference for 8 to 12 Bit D/A Converters
- Low $T_C$ Zener Replacement
- High Stability Current Reference
- MPU D/A and A/D Applications

**PRECISION LOW DRIFT VOLTAGE REFERENCES**

**5.0, 6.25, and 10–VOLT OUTPUT VOLTAGES**

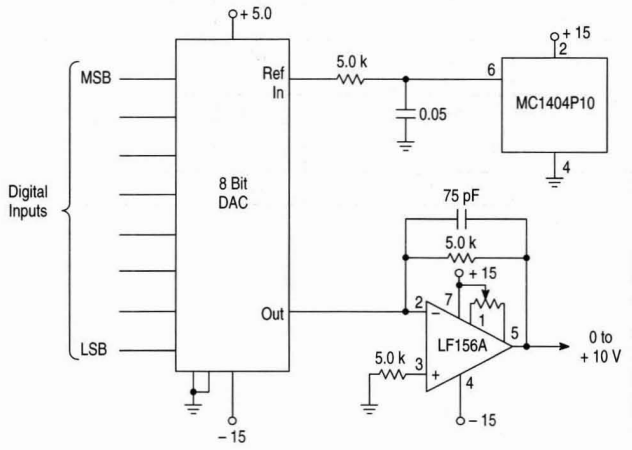
**SEMICONDUCTOR TECHNICAL DATA**

5

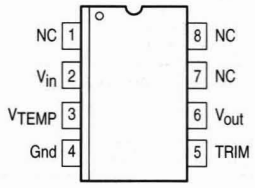



**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**Figure 1. Voltage Output 8–Bit DAC Using MC1404P10**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1404P5 | $T_A$ = 0° to +70°C | Plastic DIP |
| MC1404P6 | | Plastic DIP |
| MC1404P10 | | Plastic DIP |

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Input Voltage | $V_{in}$ | 40 | V |
| Storage Temperature | $T_{stg}$ | – 65 to + 150 | °C |
| Junction Temperature | $T_J$ | + 175 | °C |
| Operating Ambient Temperature Range | $T_A$ | 0 to + 70 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{in}$ = 15 V, $T_A$ = 25°C, and Trim Terminal not connected, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Voltage ($I_O$ = 0 mA)<br>MC1404P5<br>MC1404P6<br>MC1404P10 | $V_O$ | <br>4.95<br>6.19<br>9.9 | <br>5.0<br>6.25<br>10 | <br>5.05<br>6.31<br>10.1 | V |
| Output Voltage Tolerance | – | – | ± 0.1 | ± 1.0 | % |
| Output Trim Range (Figure 10) ($R_P$ = 100 kΩ) | $\Delta V_{TRIM}$ | ± 6.0 | – | – | % |
| Output Voltage Temperature Coefficient, Over Full Temperature Range | $\Delta V_O/\Delta T$ | – | 10 | 40 | ppm/°C |
| Maximum Output Voltage Change Over Temperature Range<br>MC1404P5<br>MC1404P6<br>MC1404P10 | $\Delta V_O$ | <br>–<br>–<br>– | <br>–<br>–<br>– | <br>14<br>17.5<br>28 | mV |
| Line Regulation (Note 1) ($V_{in}$ = $V_{out}$ + 2.5 V to 40 V, $I_{out}$ = 0 mA) | $Reg_{line}$ | – | 2.0 | 6.0 | mV |
| Load Regulation (Note 1) (0 ≤ $I_O$ ≤ 10 mA) | $Reg_{load}$ | – | – | 10 | mV |
| Quiescent Current ($I_O$ = 0 mA) | $I_Q$ | – | 1.2 | 1.5 | mA |
| Short Circuit Current | $I_{sc}$ | – | 20 | 45 | mA |
| Long Term Stability | – | – | 25 | – | ppm/1000 hrs |

**NOTE:** 1. Includes thermal effects.

**DYNAMIC CHARACTERISTICS** ($V_{in}$ = 15 V, $T_A$ = 25°C, all voltage ranges, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Turn–On Settling Time (to ± 0.01%) | $t_S$ | – | 50 | – | μs |
| Output Noise Voltage – P to P (Bandwidth 0.1 to 10 Hz) | $V_n$ | – | 12 | – | μV |
| Small–Signal Output Impedance<br>120 Hz<br>500 Hz | $r_o$ | <br>–<br>– | <br>0.15<br>0.2 | <br>–<br>– | Ω |
| Power Supply Rejection Ratio | PSRR | 70 | 80 | – | dB |

## TYPICAL CHARACTERISTICS

**Figure 2. Simplified Device Diagram**

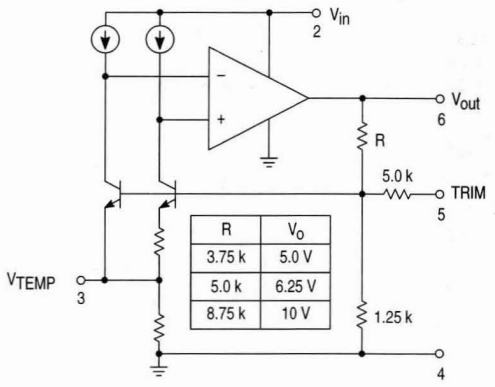



**Figure 3. Line Regulation versus Temperature**

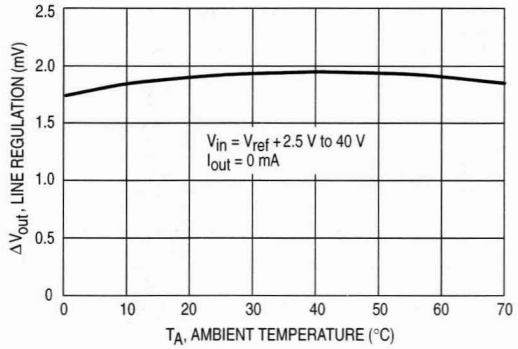



**Figure 4. Output Voltage versus Temperature MC1404P10**

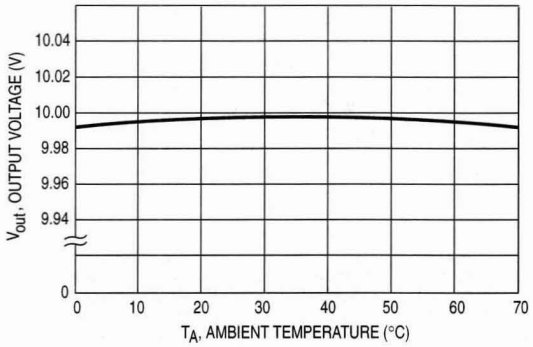



**Figure 5. Load Regulation versus Temperature**

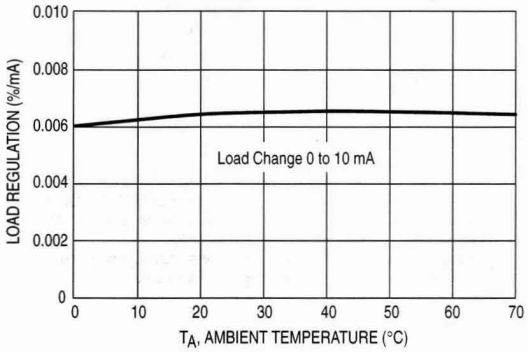



**Figure 6. Power Supply Rejection Ratio versus Frequency**

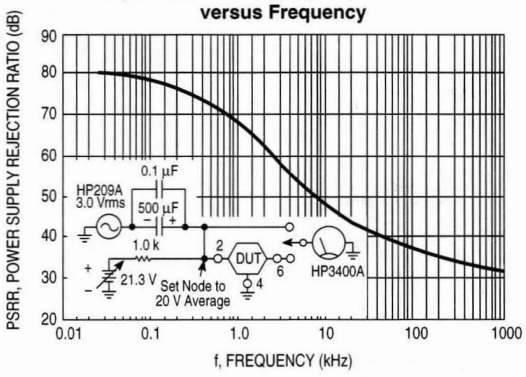



**Figure 7. Quiescent Current versus Temperature**

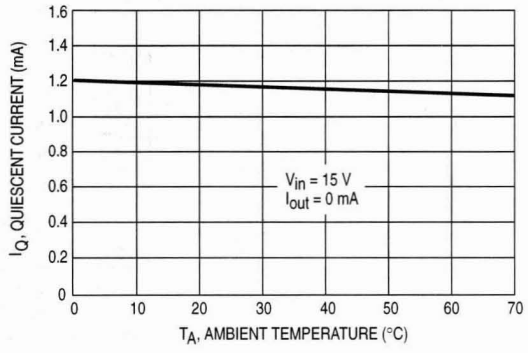



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**Figure 8. Short Circuit Current versus Temperature**

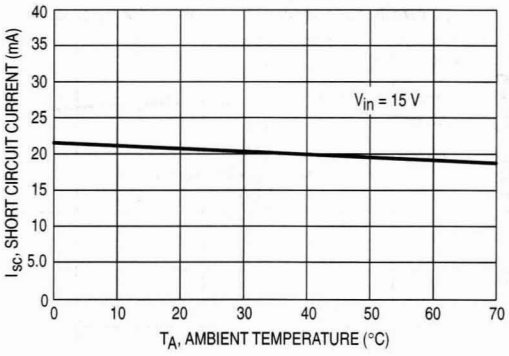
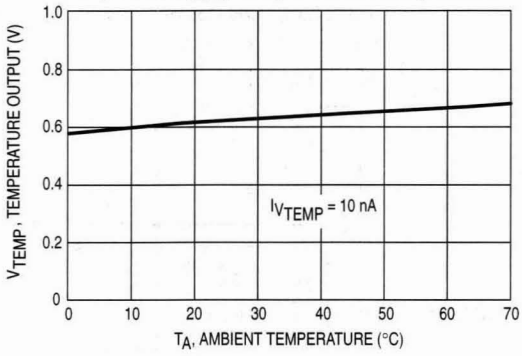
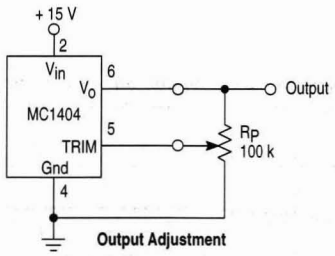



**Figure 9. $V_{TEMP}$ Output versus Temperature**




5

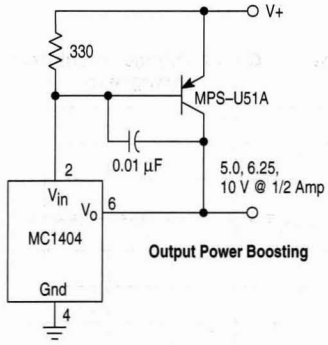
**Figure 10. Output Trim Configuration**




The MC1404 trim terminal can be used to adjust the output voltage over a ± 6.0% range. For example, the output can be set to 10.000 V or to 10.240 V for binary applications. For trimming, Bourns type 3059, 100 kΩ or 200 kΩ trimpot is recommended.

Although Figure 10 illustrates a wide trim range, temperature coefficients may become unpredictable for trim > ± 6.0%.

**Figure 11. Precision Supply Using MC1404**




The addition of a power transistor, a resistor, and a capacitor converts the MC1404 into a precision supply with one ampere current capability. At V+ = 15 V, the MC1404 can carry in excess of 14 mA of load current with good regulation. If the power transistor current gain exceeds 75, a one ampere supply can be realized.

**Figure 12. Ultra Stable Reference for MC1723 Voltage Regulator**

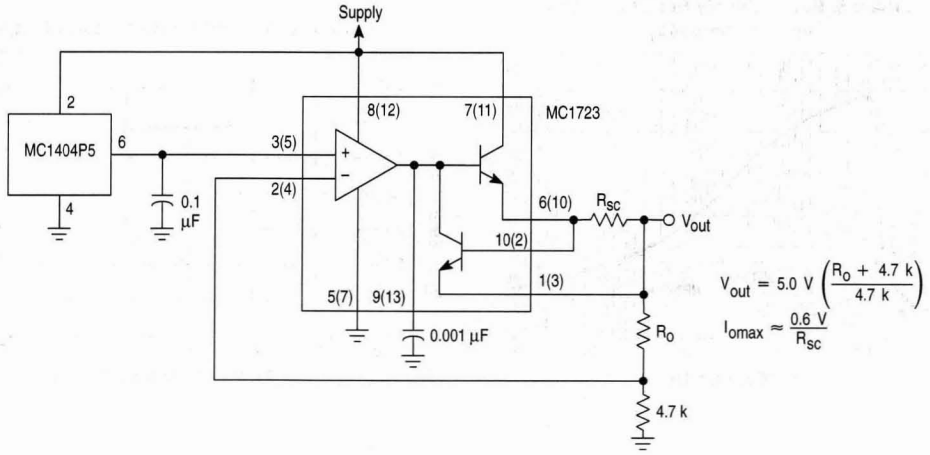


**Figure 13. 5.0 V, 6.0 Amp, 25 kHz Switching Regulator with Separate Ultra–Stable Reference**

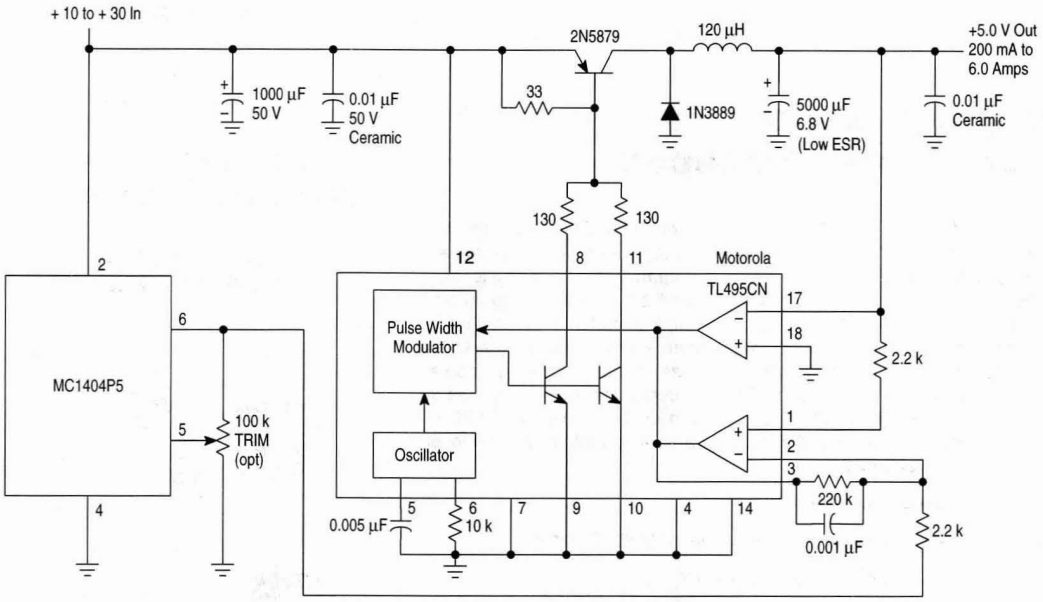
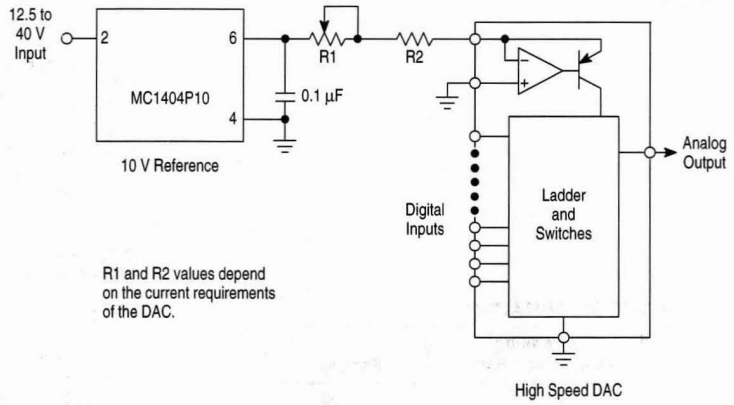



**Figure 14. Reference for a High Speed DAC**



MOTOROLA

# TL431, A, B Series

## Programmable Precision References

**PROGRAMMABLE PRECISION REFERENCES**

**SEMICONDUCTOR TECHNICAL DATA**

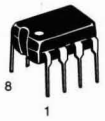
5

The TL431, A, B integrated circuits are three–terminal programmable shunt regulator diodes. These monolithic IC voltage references operate as a low temperature coefficient zener which is programmable from $V_{ref}$ to 36 V with two external resistors. These devices exhibit a wide operating current range of 1.0 mA to 100 mA with a typical dynamic impedance of 0.22 Ω. The characteristics of these references make them excellent replacements for zener diodes in many applications such as digital voltmeters, power supplies, and op amp circuitry. The 2.5 V reference makes it convenient to obtain a stable reference from 5.0 V logic supplies, and since the TL431, A, B operates as a shunt regulator, it can be used as either a positive or negative voltage reference.

- Programmable Output Voltage to 36 V
- Voltage Reference Tolerance: ±0.4%, Typ @ 25°C (TL431B)
- Low Dynamic Output Impedance, 0.22 Ω Typical
- Sink Current Capability of 1.0 mA to 100 mA
- Equivalent Full–Range Temperature Coefficient of 50 ppm/°C Typical
- Temperature Compensated for Operation over Full Rated Operating Temperature Range
- Low Output Noise Voltage

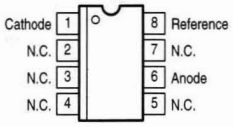
**Z, LP SUFFIX**
PLASTIC PACKAGE
CASE 29
(TO–92)

Pin 1. Reference
2. Anode
3. Cathode



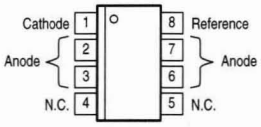

**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**DM SUFFIX**
PLASTIC PACKAGE
CASE 846A
(Micro–8)




(Top View)

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SOP–8)



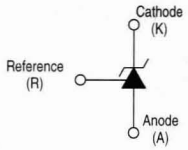

(Top View)

SOP–8 is an internally modified SO–8 package. Pins 2, 3, 6 and 7 are electrically common to the die attach flag. This internal lead frame modification decreases power dissipation capability when appropriately mounted on a printed circuit board. SOP–8 conforms to all external dimensions of the standard SO–8 package.

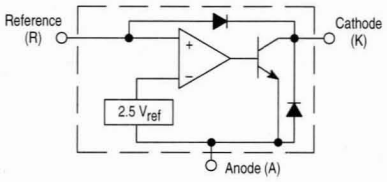
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| TL431CLP, ACLP, BCLP | $T_A$ = 0° to +70°C | TO–92 |
| TL431CP, ACP, BCP | | Plastic |
| TL431CDM, ACDM, BCDM | | Micro–8 |
| TL431CD, ACD, BCD | | SOP–8 |
| TL431ILP, AILP, BILP | $T_A$ = –40° to +85°C | TO–92 |
| TL431IP, AIP, BIP | | Plastic |
| TL431IDM, AIDM, BIDM | | Micro–8 |
| TL431ID, AID, BID | | SOP–8 |

**Symbol**

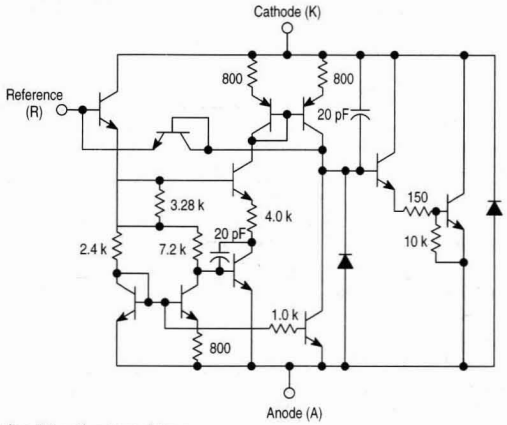



**Representative Block Diagram**




**Representative Schematic Diagram**

Component values are nominal




This device contains 12 active transistors.

**MAXIMUM RATINGS** (Full operating ambient temperature range applies, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Cathode to Anode Voltage | $V_{KA}$ | 37 | V |
| Cathode Current Range, Continuous | $I_K$ | –100 to +150 | mA |
| Reference Input Current Range, Continuous | $I_{ref}$ | –0.05 to +10 | mA |
| Operating Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range<br>TL431I, TL431AI, TL431BI<br>TL431C, TL431AC, TL431BC | $T_A$ | <br>–40 to +85<br>0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Total Power Dissipation @ $T_A$ = 25°C<br>Derate above 25°C Ambient Temperature<br>D, LP Suffix Plastic Package<br>P Suffix Plastic Package<br>DM Suffix Plastic Package | $P_D$ | <br><br>0.70<br>1.10<br>0.52 | W |
| Total Power Dissipation @ $T_C$ = 25°C<br>Derate above 25°C Case Temperature<br>D, LP Suffix Plastic Package<br>P Suffix Plastic Package | $P_D$ | <br><br>1.5<br>3.0 | W |

**NOTE:** ESD data available upon request.

**RECOMMENDED OPERATING CONDITIONS**

| Condition | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Cathode to Anode Voltage | $V_{KA}$ | $V_{ref}$ | 36 | V |
| Cathode Current | $I_K$ | 1.0 | 100 | mA |

**THERMAL CHARACTERISTICS**

| Characteristic | Symbol | D, LP Suffix Package | P Suffix Package | DM Suffix Package | Unit |
|---|---|---|---|---|---|
| Thermal Resistance, Junction–to–Ambient | $R_{\theta JA}$ | 178 | 114 | 240 | °C/W |
| Thermal Resistance, Junction–to–Case | $R_{\theta JC}$ | 83 | 41 | – | °C/W |



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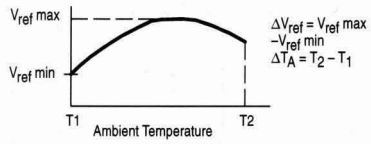
**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | TL431I | | | TL431C | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | |
| Reference Input Voltage (Figure 1)<br>$V_{KA} = V_{ref}$, $I_K$ = 10 mA<br>$T_A$ = 25°C<br>$T_A = T_{low}$ to $T_{high}$ (Note 1) | $V_{ref}$ | <br><br>2.44<br>2.41 | <br><br>2.495<br>– | <br><br>2.55<br>2.58 | <br><br>2.44<br>2.423 | <br><br>2.495<br>– | <br><br>2.55<br>2.567 | V |
| Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 1, 2, 4)<br>$V_{KA} = V_{ref}$, $I_K$ = 10 mA | $\Delta V_{ref}$ | – | 7.0 | 30 | – | 3.0 | 17 | mV |
| Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage<br>$I_K$ = 10 mA (Figure 2), $\Delta V_{KA}$ = 10 V to $V_{ref}$<br>$\Delta V_{KA}$ = 36 V to 10 V | $\frac{\Delta V_{ref}}{\Delta V_{KA}}$ | <br>–<br>– | <br>–1.4<br>–1.0 | <br>–2.7<br>–2.0 | <br>–<br>– | <br>–1.4<br>–1.0 | <br>–2.7<br>–2.0 | mV/V |
| Reference Input Current (Figure 2)<br>$I_K$ = 10 mA, R1 = 10 k, R2 = ∞<br>$T_A$ = 25°C<br>$T_A = T_{low}$ to $T_{high}$ (Note 1) | $I_{ref}$ | <br>–<br>– | <br>1.8<br>– | <br>4.0<br>6.5 | <br>–<br>– | <br>1.8<br>– | <br>4.0<br>5.2 | µA |
| Reference Input Current Deviation Over Temperature Range (Figure 2, Note 1, 4)<br>$I_K$ = 10 mA, R1 = 10 k, R2 = ∞ | $\Delta I_{ref}$ | – | 0.8 | 2.5 | – | 0.4 | 1.2 | µA |
| Minimum Cathode Current For Regulation<br>$V_{KA} = V_{ref}$ (Figure 1) | $I_{min}$ | – | 0.5 | 1.0 | – | 0.5 | 1.0 | mA |
| Off–State Cathode Current (Figure 3)<br>$V_{KA}$ = 36 V, $V_{ref}$ = 0 V | $I_{off}$ | – | 2.6 | 1000 | – | 2.6 | 1000 | nA |
| Dynamic Impedance (Figure 1, Note 3)<br>$V_{KA} = V_{ref}$, $\Delta I_K$ = 1.0 mA to 100 mA<br>f ≤ 1.0 kHz | $\lvert Z_{KA} \rvert$ | – | 0.22 | 0.5 | – | 0.22 | 0.5 | Ω |

**NOTE 1:** $T_{low}$ = –40°C for TL431AIP TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431AIDM, TL431IDM, TL431BIDM
= 0°C for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CD, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
$T_{high}$ = +85°C for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431IDM, TL431AIDM, TL431BIDM
= +70°C for TL431ACP, TL431ACLP, TL431CP, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM

**NOTE 2:** The deviation parameter $\Delta V_{ref}$ is defined as the difference between the maximum and minimum values obtained over the full operating ambient temperature range that applies.




The average temperature coefficient of the reference input voltage, $\alpha V_{ref}$ is defined as:

$$V_{ref}\ \frac{ppm}{°C} = \frac{\left(\frac{\Delta V_{ref}}{V_{ref}\ @\ 25°C}\right) X\ 10^6}{\Delta T_A} = \frac{\Delta V_{ref} \times 10^6}{\Delta T_A\ (V_{ref}\ @\ 25°C)}$$

$\alpha V_{ref}$ can be positive or negative depending on whether $V_{ref}$ Min or $V_{ref}$ Max occurs at the lower ambient temperature. (Refer to Figure 6.)

Example : $\Delta V_{ref}$ = 8.0 mV and slope is positive,
$V_{ref}$ @ 25°C = 2.495 V, $\Delta T_A$ = 70°C $\qquad \alpha V_{ref} = \frac{0.008 \times 10^6}{70\ (2.495)} = 45.8$ ppm/°C

**NOTE 3 :** The dynamic impedance $Z_{KA}$ is defined as $\lvert Z_{KA} \rvert = \frac{\Delta V_{KA}}{\Delta I_K}$

When the device is programmed with two external resistors, R1 and R2, (refer to Figure 2) the total dynamic impedance of the circuit is defined as:

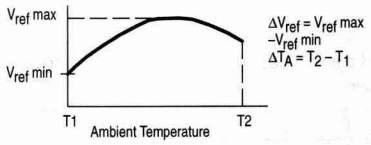
$$\lvert Z_{KA}' \rvert \approx \lvert Z_{KA} \rvert \left(1 + \frac{R1}{R2}\right)$$

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | TL431AI | | | TL431AC | | | TL431B | | | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | |
| Reference Input Voltage (Figure 1)<br>$V_{KA} = V_{ref}$, $I_K$ = 10 mA<br>$T_A$ = 25°C<br>$T_A = T_{low}$ to $T_{high}$ | $V_{ref}$ | <br><br>2.47<br>2.44 | <br><br>2.495<br>– | <br><br>2.52<br>2.55 | <br><br>2.47<br>2.453 | <br><br>2.495<br>– | <br><br>2.52<br>2.537 | <br><br>2.483<br>2.475 | <br><br>2.495<br>2.495 | <br><br>2.507<br>2.515 | V |
| Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 1, 2, 4)<br>$V_{KA} = V_{ref}$, $I_K$ = 10 mA | $\Delta V_{ref}$ | – | 7.0 | 30 | – | 3.0 | 17 | – | 3 | 17 | mV |
| Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage<br>$I_K$ = 10 mA (Figure 2), $\Delta V_{KA}$ = 10 V to $V_{ref}$<br>$\Delta V_{KA}$ = 36 V to 10 V | $\frac{\Delta V_{ref}}{\Delta V_{KA}}$ | <br>–<br>– | <br>–1.4<br>–1.0 | <br>–2.7<br>–2.0 | <br>–<br>– | <br>–1.4<br>–1.0 | <br>–2.7<br>–2.0 | <br>–<br>– | <br>–1.4<br>–1.0 | <br>–2.7<br>–2.0 | mV/V |
| Reference Input Current (Figure 2)<br>$I_K$ = 10 mA, R1 = 10 k, R2 = ∞<br>$T_A$ = 25°C<br>$T_A = T_{low}$ to $T_{high}$ (Note 1) | $\Delta I_{ref}$ | <br>–<br>– | <br>1.8<br>– | <br>4.0<br>6.5 | <br>–<br>– | <br>1.8<br>– | <br>4.0<br>5.2 | <br>–<br>– | <br>1.6<br>– | <br>3.0<br>4.0 | µA |
| Reference Input Current Deviation Over Temperature Range (Figure 2, Note 1)<br>$I_K$ = 10 mA, R1 = 10 k, R2 = ∞ | $\Delta I_{ref}$ | – | 0.8 | 2.5 | – | 0.4 | 1.2 | – | 0.4 | 1.2 | µA |
| Minimum Cathode Current For Regulation<br>$V_{KA} = V_{ref}$ (Figure 1) | $I_{min}$ | – | 0.5 | 1.0 | – | 0.5 | 1.0 | – | 0.5 | 1.0 | mA |
| Off–State Cathode Current (Figure 3)<br>$V_{KA}$ = 36 V, $V_{ref}$ = 0 V | $I_{off}$ | – | 260 | 1000 | – | 260 | 1000 | – | 230 | 500 | nA |
| Dynamic Impedance (Figure 1, Note 3)<br>$V_{KA} = V_{ref}$, $\Delta I_K$ = 1.0 mA to 100 mA<br>f ≤ 1.0 kHz | $\lvert Z_{KA} \rvert$ | – | 0.22 | 0.5 | – | 0.22 | 0.5 | – | 0.14 | 0.3 | Ω |

**NOTE 1:** $T_{low}$ = –40°C for TL431AIP TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431AIDM, TL431IDM, TL431BIDM
= 0°C for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CD, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
$T_{high}$ = +85°C for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431IDM, TL431AIDM, TL431BIDM
= +70°C for TL431ACP, TL431ACLP, TL431CP, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM

**NOTE 2:** The deviation parameter $\Delta V_{ref}$ is defined as the difference between the maximum and minimum values obtained over the full operating ambient temperature range that applies.




The average temperature coefficient of the reference input voltage, $\alpha V_{ref}$ is defined as:

$$V_{ref}\ \frac{ppm}{°C} = \frac{\left(\frac{\Delta V_{ref}}{V_{ref}\ @\ 25°C}\right) \times 10^6}{\Delta T_A} = \frac{\Delta V_{ref} \times 10^6}{\Delta T_A\ (V_{ref}\ @\ 25°C)}$$

$\alpha V_{ref}$ can be positive or negative depending on whether $V_{ref}$ Min or $V_{ref}$ Max occurs at the lower ambient temperature. (Refer to Figure 6.)

Example : $\Delta V_{ref}$ = 8.0 mV and slope is positive,

$V_{ref}$ @ 25°C = 2.495 V, $\Delta T_A$ = 70°C $\qquad \alpha V_{ref} = \frac{0.008 \times 10^6}{70\ (2.495)} = 45.8$ ppm/°C

**NOTE 3 :** The dynamic impedance $Z_{KA}$ is defined as $\lvert Z_{KA} \rvert = \frac{\Delta V_{KA}}{\Delta I_K}$

When the device is programmed with two external resistors, R1 and R2, (refer to Figure 2) the total dynamic impedance of the circuit is defined as:

$$\lvert Z_{KA}' \rvert \approx \lvert Z_{KA} \rvert \left(1 + \frac{R1}{R2}\right)$$

**NOTE 4:** This test is not applicable to surface mount (D and DM suffix) devices.

**Figure 1. Test Circuit for $V_{KA} = V_{ref}$**

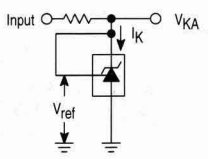



**Figure 2. Test Circuit for $V_{KA} > V_{ref}$**

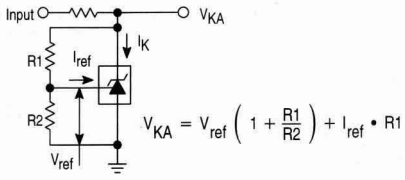



**Figure 3. Test Circuit for $I_{of}$**

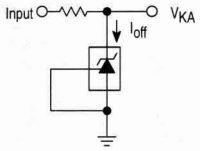



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**Figure 4. Cathode Current versus Cathode Voltage**

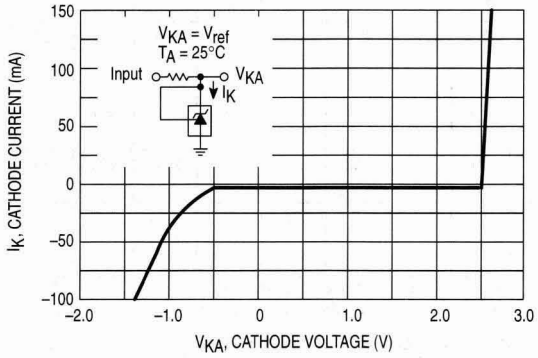


**Figure 5. Cathode Current versus Cathode Voltage**

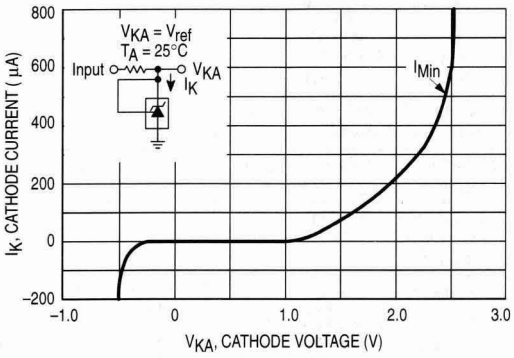


**Figure 6. Reference Input Voltage versus Ambient Temperature**

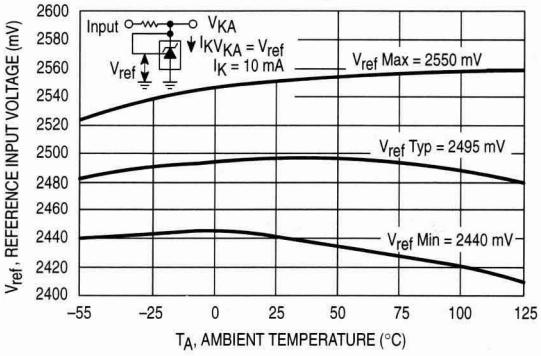


**Figure 7. Reference Input Current versus Ambient Temperature**

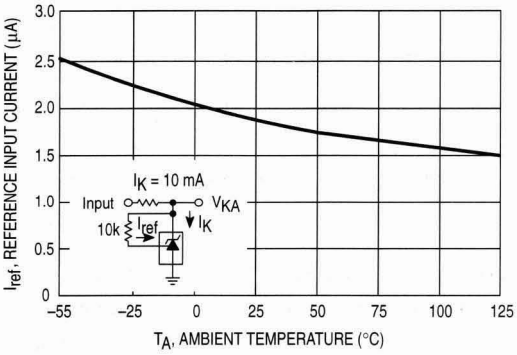

**Figure 8. Change in Reference Input Voltage versus Cathode Voltage**

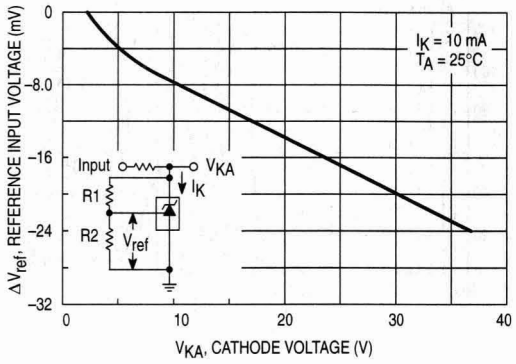


**Figure 9. Off–State Cathode Current versus Ambient Temperature**

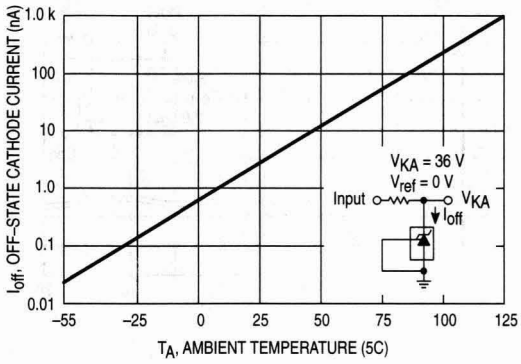


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**Figure 10. Dynamic Impedance versus Frequency**

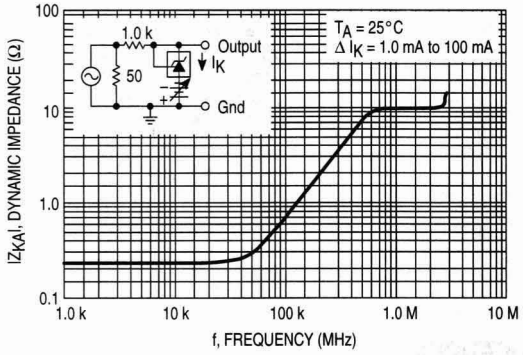


**Figure 11. Dynamic Impedance versus Ambient Temperature**

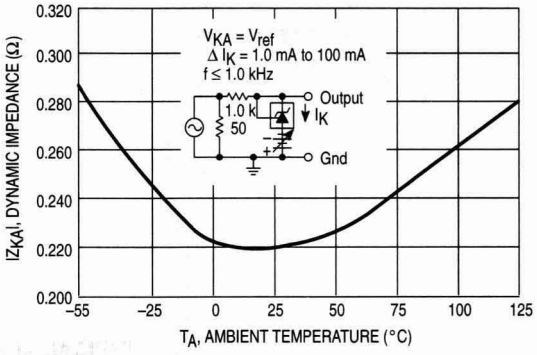


**Figure 12. Open–Loop Voltage Gain versus Frequency**

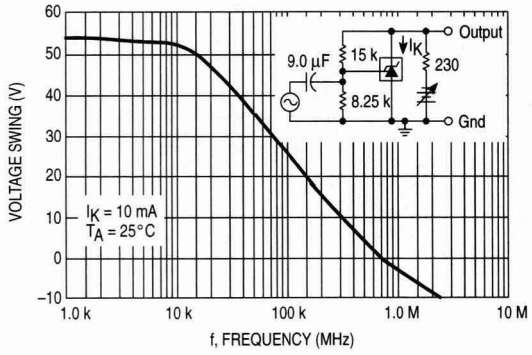


**Figure 13. Spectral Noise Density**

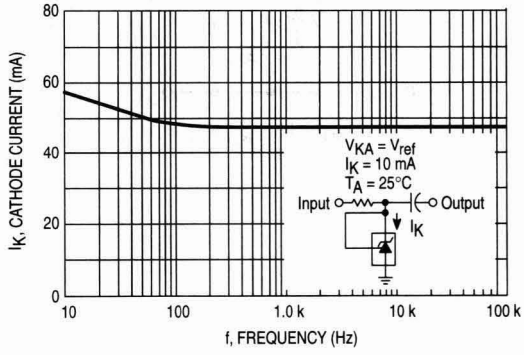

**Figure 14. Pulse Response**

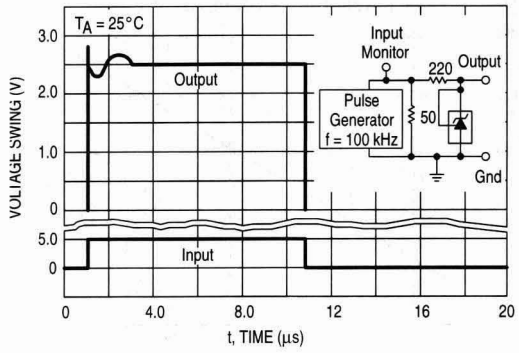


**Figure 15. Stability Boundary Conditions**

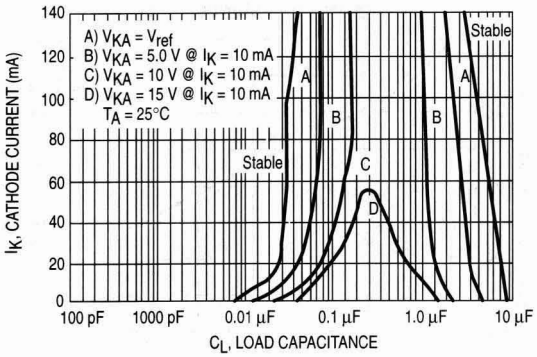


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**Figure 16. Test Circuit For Curve A of Stability Boundary Conditions**

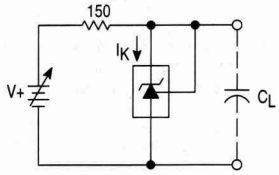
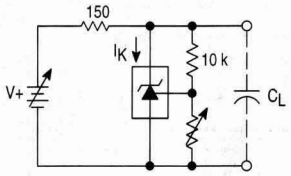



**Figure 17. Test Circuit For Curves B, C, And D of Stability Boundary Conditions**




## TYPICAL APPLICATIONS

**Figure 18. Shunt Regulator**

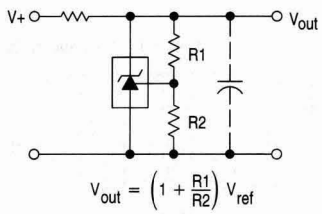



**Figure 19. High Current Shunt Regulator**

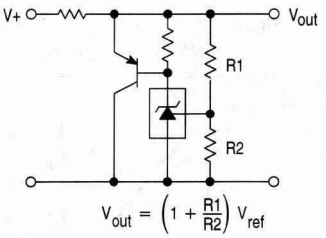
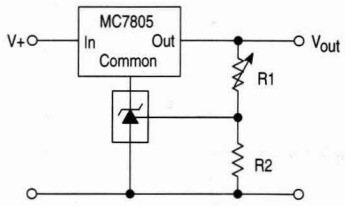


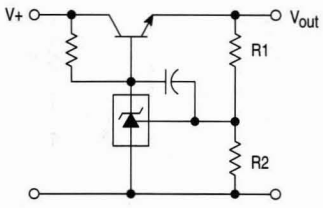
**Figure 20. Output Control for a Three–Terminal Fixed Regulator**




$$V_{out} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

$$V_{out\ min} = V_{ref} + 5.0V$$

**Figure 21. Series Pass Regulator**

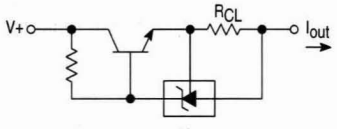



$$V_{out} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

$$V_{out\ min} = V_{ref} + V_{be}$$

5

**Figure 22. Constant Current Source**




$$I_{out} = \frac{V_{ref}}{R_{CL}}$$

**Figure 23. Constant Current Sink**

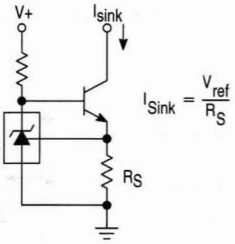
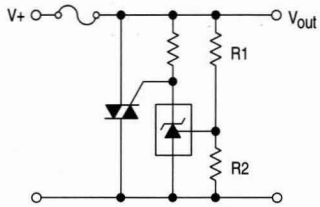
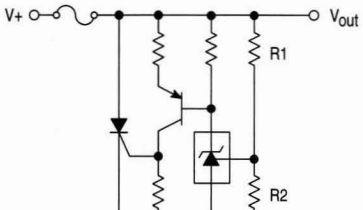



**Figure 24. TRIAC Crowbar**



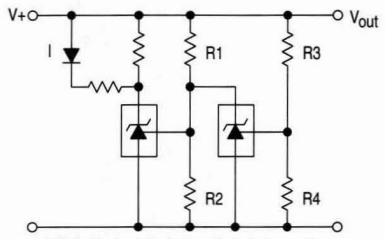

$$V_{out(trip)} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

**Figure 25. SRC Crowbar**




$$V_{out(trip)} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

**Figure 26. Voltage Monitor**

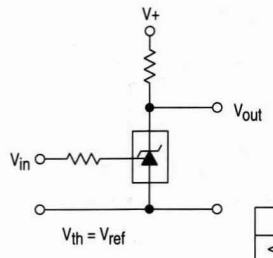



L.E.D. indicator is 'on' when V+ is between the upper and lower limits.

$$\text{Lower Limit} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

$$\text{Upper Limit} = \left(1 + \frac{R3}{R4}\right) V_{ref}$$

**Figure 27. Single–Supply Comparator with Temperature–Compensated Threshold**




| $V_{in}$ | $V_{out}$ |
|---|---|
| < $V_{ref}$ | V+ |
| > $V_{ref}$ | ≈ 2.0 V |

**Figure 28. Linear Ohmmeter**

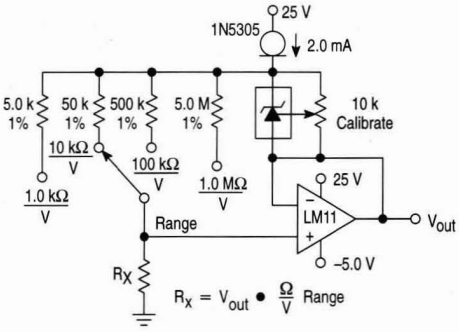



**Figure 29. Simple 400 mW Phono Amplifier**

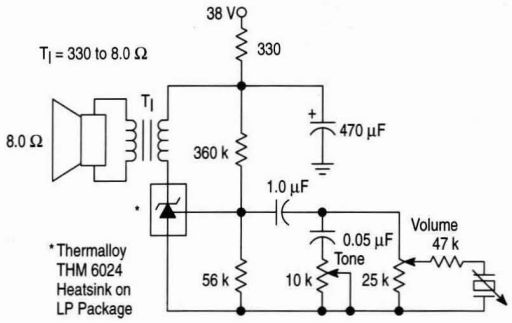
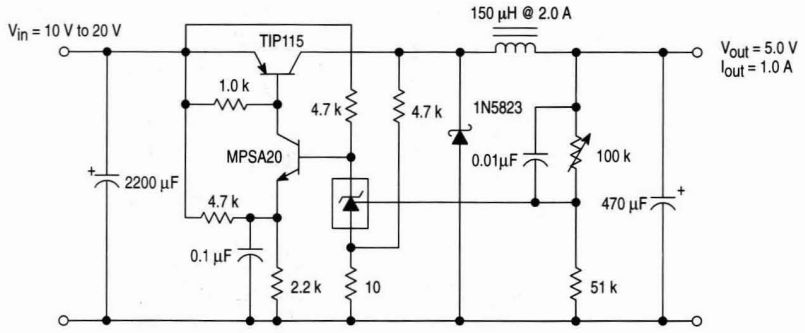


**Figure 30. High Efficiency Step–Down Switching Converter**




| Test | Conditions | Results |
|---|---|---|
| Line Regulation | $V_{in}$ = 10 V to 20 V, $I_o$ = 1.0 A | 53 mV (1.1%) |
| Load Regulation | $V_{in}$ = 15 V, $I_o$ = 0 A to 1.0 A | 25 mV (0.5%) |
| Output Ripple | $V_{in}$ = 10 V, $I_o$ = 1.0 A | 50 mVpp P.A.R.D. |
| Output Ripple | $V_{in}$ = 20 V, $I_o$ = 1.0 A | 100 mVpp P.A.R.D. |
| Efficiency | $V_{in}$ = 15 V, $I_o$ = 1.0 A | 82% |

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# Data Conversion

## In Brief . . .

Motorola's line of digital–to–analog and analog–to–digital converters include several varieties to suit a number of applications.

The A/D converters include an 8–bit flash converter suitable for NTSC and PAL systems. CMOS devices include 8 to 10–bit converters, as well as other high speed digitizers.

The D/A converters have 6 and 8–bit devices, and video speed (for NTSC and PAL) devices.


| | Page |
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| Data Conversion | 6–2 |
| A–D Converters | 6–2 |
| CMOS | 6–2 |
| Bipolar | 6–2 |
| Sigma–Delta | 6–2 |
| D–A Converters | 6–3 |
| CMOS | 6–3 |
| Sigma–Delta | 6–3 |
| Package Overview | 6–4 |
| Device Listing and Related Literature | 6–5 |

# Data Conversion

The line of data conversion products which Motorola offers spans a wide spectrum of speed and resolution/accuracy. Features, including bus compatibility, minimize external parts count and provide easy interface to microprocessor systems. Various technologies, such as Bipolar and CMOS, are utilized to achieve functional capability, accuracy and production repeatability. Bipolar technology generally results in higher speed, while CMOS devices offer greatly reduced power consumption.



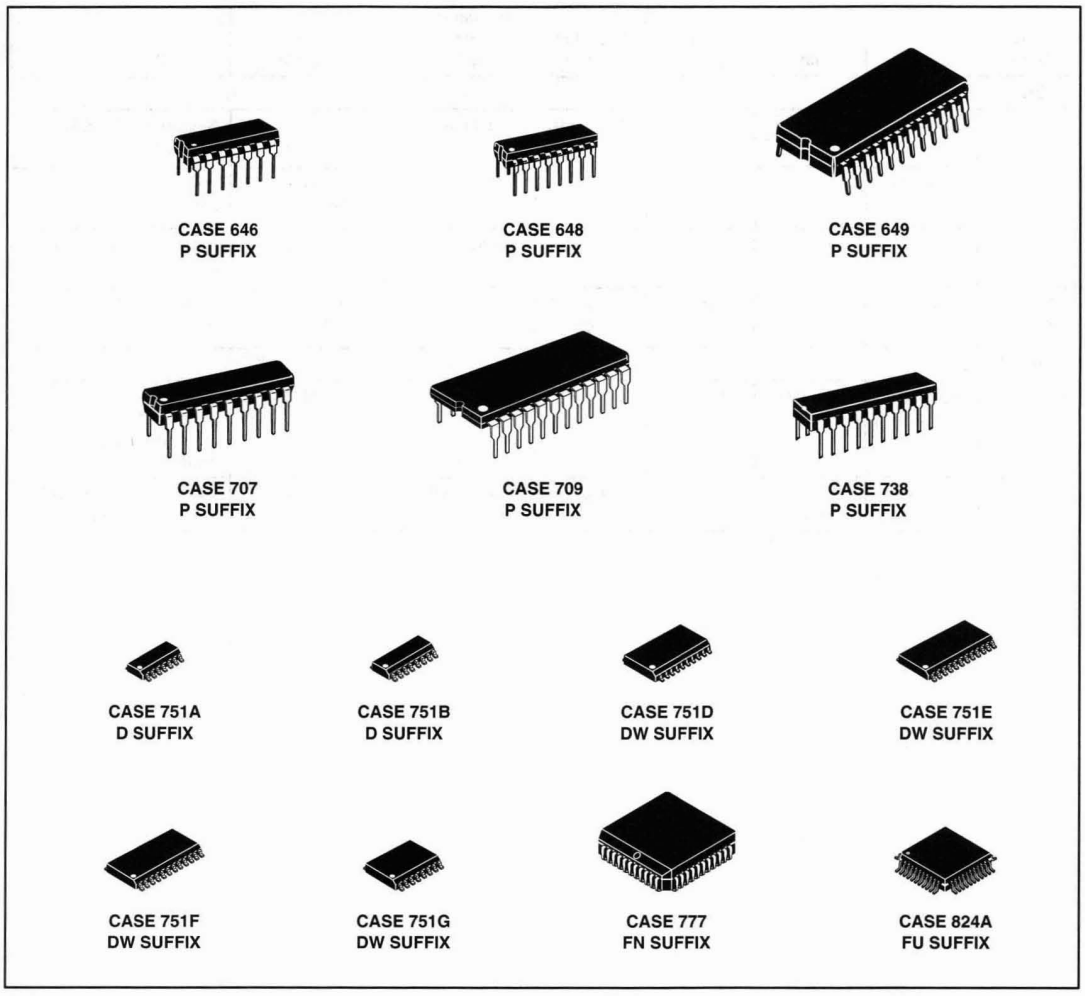
**Table 1. A–D Converters**

| Resolution (Bits) | Device | Nonlinearity Max | Conversion Time/Rate | Input Voltage Range | Supplies (V) | Temperature Range (°C) | Suffix/ Package | Comments |
|---|---|---|---|---|---|---|---|---|
| **CMOS** | | | | | | | | |
| 8 | MC145040 | ±1/2 LSB | 10 µs | 0 to $V_{DD}$ | +5.0 ±10% | –40 to +125 | P/738, DW/751D | Requires External Clock, 11–Ch MUX |
| | MC145041 | | 20 µs | | | | | Includes Internal Clock, 11–Ch MUX |
| | MC14549B/ MC14559B | Successive Approximation Registers | | | +3.0 to +18 | –40 to +85 | P/648 | Compatible with MC1408 S.A.R. 8–bit D–A Converter |
| Triple 8–Bit | MC44251 | 1 LSB | 18 MHz | 1.6 to 4.6 V | +5.0 ±10% | –40 to +85 | FN/777 | 3 Separate Video Channels |
| 10 | MC145050 | ±1 LSB | 21 µs | 0 to $V_{DD}$ | +5.0 ±10% | –40 to +125 | P/738, DW/751D | Requires External Clock, 11–Ch MUX |
| | MC145051 | | 44 µs | | | | | Includes Internal Clock, 11–Ch MUX |
| | MC145053 | | | | | | P/646, D/751A | Includes Internal Clock, 5–Ch MUX |
| 8–10 | MC14443/ MC14447 | ±0.5% Full Scale | 300 µs | Variable w/Supply | +5.0 to +18 | –40 to +85 | P/648, DW/751G | µP Compatible, Single Slope, 6–Ch MUX |
| 3–1/2 Digit | MC14433 | ±0.05% ±1 Count | 40 ms | ±2.0 V ±200 mV | +5.0 to +8.0 –2.8 to –8.0 | | P/709, DW/751E | Dual Slope |
| **Bipolar** | | | | | | | | |
| 8 | MC10319 | ±1 LSB | 25 MHz | 0 to 2.0 Vpp Max | +5.0 and –3.0 to –6.0 | 0 to +70 | P/709, DW/751F Die Form | Video Speed Flash Converter, Internal Gray Code TTL Outputs |
| **Sigma–Delta** | | | | | | | | |
| 16 | MC145073 | ±1 LSB | 48 kHz | 1.9 Vpp | 4.5 to 5.5 | –40 to +85 | DW/751E | Dual Channel, Sigma–Delta architecture |

## Table 2. D–A Converters

| Resolution (Bits) | Device | Accuracy @ 25°C Max | Max Settling Time (± 1/2 LSB) | Supplies (V) | Temperature Range (°C) | Suffix/ Package | Comments |
|---|---|---|---|---|---|---|---|
| **CMOS** | | | | | | | |
| 6 | MC144110 | – | – | +5.0 to +15 | 0 to +85 | P/707, DW/751D | Serial input, Hex DAC, 6 outputs |
| | MC144111 | – | – | | | P/646, DW/751G | Serial input, Quad DAC, 4 outputs |
| | MC144112 | – | – | +2.5 to +5.5 | –40 to +85 | P/646, D/751A | Serial input, Quad DAC, 4 outputs |
| Triple 8–Bit | MC44200 | ±1/2 LSB | 30 ns | +5.0 ±10% | –40 to +85 | FU/824A | Triple Video DAC, 55 MHz, TTL |
| **Sigma–Delta** | | | | | | | |
| 16, 18, 20 | MC145074 | See data sheet | 6.0 ns | 4.5 to 5.5 | –40 to +85 | D/751B | Dual Channel, Sigma–Delta architecture, MC145076 FIR Filter available |
| – | MC145076 | See data sheet | – | +5.0 | –40 to +85 | D/751B | Dual Channel Bit Stream, 144 tap FIR Filter |

# Data Conversion Package Overview



CASE 646
P SUFFIX

CASE 648
P SUFFIX

CASE 649
P SUFFIX

CASE 707
P SUFFIX

CASE 709
P SUFFIX

CASE 738
P SUFFIX

CASE 751A
D SUFFIX

CASE 751B
D SUFFIX

CASE 751D
DW SUFFIX

CASE 751E
DW SUFFIX

CASE 751F
DW SUFFIX

CASE 751G
DW SUFFIX

CASE 777
FN SUFFIX

CASE 824A
FU SUFFIX

# Device Listing and Related Literature

## A–D Converters


| Device | Function | Page |
|---|---|---|
| **MC10319** | High Speed 8–Bit Analog–to–Digital Flash Converter | 6–6 |


## RELATED APPLICATION NOTES

| App Note | Title | Related Device |
|---|---|---|
| AN702 | High Speed Digital–to–Analog and Analog–to–Digital Techniques | **General Information** |
| AN926 | Techniques for Improving the Settling Time of a DAC and Op Amp Combination | **Various** |

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MOTOROLA

# MC10319

# High Speed 8-Bit Analog-to-Digital Converter

**HIGH SPEED 8–BIT ANALOG–TO–DIGITAL FLASH CONVERTER**

**SEMICONDUCTOR TECHNICAL DATA**

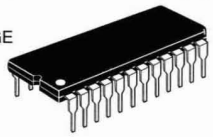
The MC10319 is an 8–bit high speed parallel flash A/D converter. The device employs an internal Grey Code structure to eliminate large output errors on fast slewing input signals. It is fully TTL compatible, requiring a + 5.0 V supply and a wide tolerance negative supply of – 3.0 to – 6.0 V. Three–state TTL outputs allow direct drive of a data bus or common I/O memory.

The MC10319 contains 256 parallel comparators across a precision input reference network. The comparator outputs are fed to latches and then to an encoder network, to produce an 8–bit data byte plus an overrange bit. The data is latched and converted to 3–state LS–TTL outputs. The overrange bit is always active to allow for either sensing of the overrange condition or ease of interconnecting a pair of devices to produce a 9–bit A/D converter.

Applications include video display and radar processing, high speed instrumentation and TV broadcast encoding.

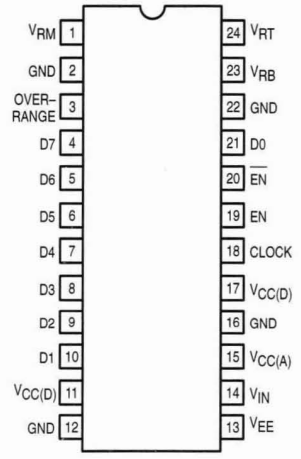
- Internal Grey Code for Speed and Accuracy, Binary Outputs
- 8–Bit Resolution/9–Bit Typical Accuracy
- Easily Interconnected for 9–Bit Conversion
- 3–State LS–TTL Outputs with True/Complement Enable Inputs
- 25 MHz Sampling Rate
- Wide Input Range: 1.0 to 2.0 $V_{pp}$, between ± 2.0 V
- Low Input Capacitance: 50 pF
- Low Power Dissipation: 618 mW
- No Sample/Hold Required for Video Bandwidth Signals
- Single Clock Cycle Conversion

**P SUFFIX**
PLASTIC PACKAGE
CASE 709

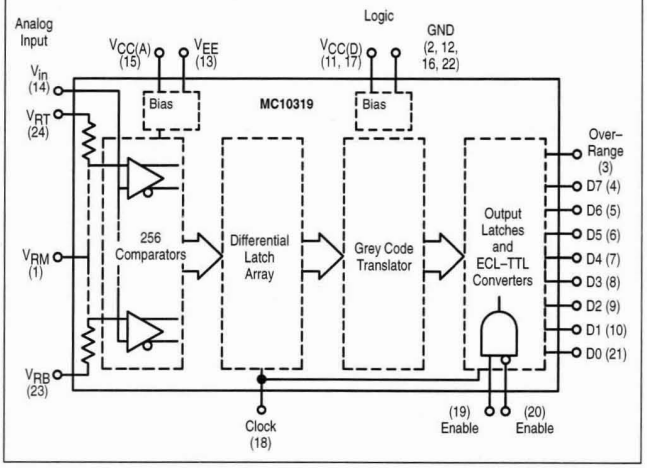


**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F
(SO–28L)

**PIN CONNECTIONS**
(P only)




**Representative Block Diagram**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC10319DW | $T_A$ = 0° to +70°C | SO–28L |
| MC10319P | | Plastic |

## ABSOLUTE MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC(A),(D)}$<br>$V_{EE}$ | + 7.0<br>– 7.0 | Vdc |
| Positive Supply Voltage Differential | $V_{CC(D)}$–<br>$V_{CC(A)}$ | – 0.3 to + 0.3 | Vdc |
| Digital Input Voltage (Pins 18 to 20) | $V_{I(D)}$ | – 0.5 to + 7.0 | Vdc |
| Analog Input Voltage (Pins 1, 14, 23, 24) | $V_{I(A)}$ | – 2.5 to + 2.5 | Vdc |
| Reference Voltage Span (Pin 24 to Pin 23) | – | 2.3 | Vdc |
| Applied Output Voltage (Pins 4 to 10, 21 in 3–State) | – | – 0.3 to + 7.0 | Vdc |
| Junction Temperature | $T_J$ | + 150 | °C |
| Storage Temperature | $T_{stg}$ | – 65 to + 150 | °C |

Devices should not be operated at these values. The "Recommended Operating Limits" table provides guidelines for actual device operation.

## RECOMMENDED OPERATING LIMITS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage (Pin 15)<br>(Pins 11, 17) | $V_{CC(A)}$<br>$V_{CC(D)}$ | + 4.5 | + 5.0 | + 5.5 | Vdc |
| $V_{CC(D)} - V_{CC(A)}$ | $\Delta V_{CC}$ | – 0.1 | 0 | + 0.1 | Vdc |
| Power Supply Voltage (Pin 13) | $V_{EE}$ | – 6.0 | – 5.0 | – 3.0 | Vdc |
| Digital Input Voltages (Pins 18 to 20) | $V_{I(D)}$ | 0 | – | + 5.0 | Vdc |
| Analog Input (Pin 14) | $V_{I(A)}$ | – 2.1 | – | + 2.1 | Vdc |
| Voltage @ $V_{RT}$ (Pin 24) | $V_{RT}$ | – 1.0 | – | + 2.1 | Vdc |
| Voltage @ $V_{RB}$ (Pin 23) | $V_{RB}$ | – 2.1 | – | + 1.0 | Vdc |
| $V_{RT} - V_{RB}$ | $\Delta V_R$ | + 1.0 | – | + 2.1 | Vdc |
| $V_{RB} - V_{EE}$ | – | 1.3 | – | – | Vdc |
| Applied Output Voltage (Pins 4 to 10, 21 in 3–State) | $V_o$ | 0 | – | 5.5 | Vdc |
| Clock Pulse Width – High<br>Low | $t_{CKH}$<br>$t_{CKL}$ | 5.0<br>15 | 20<br>20 | –<br>– | ns |
| Clock Frequency | $f_{CLK}$ | 0 | – | 25 | MHz |
| Operating Ambient Temperature | $T_A$ | 0 | – | + 70 | °C |

## ELECTRICAL CHARACTERISTICS ($0° < T_A < 70°C$, $V_{CC}$ = 5.0 V, $V_{EE}$ = – 5.2 V, $V_{RT}$ = +1.0 V, $V_{RB}$ = – 1.0 V, unless noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **TRANSFER CHARACTERISTICS** ($f_{CKL}$ = 25 MHz) | | | | | |
| Resolution | N | – | – | 8.0 | Bits |
| Monotonicity | MON | | Guaranteed | | Bits |
| Integral Nonlinearity | INL | – | ± 1/4 | ± 1.0 | LSB |
| Differential Nonlinearity | DNL | – | – | ± 1.0 | LSB |
| Differential Phase (See Figure 16) | DP | – | 1 | – | Deg. |
| Differential Gain (See Figure 16) | DG | – | 1 | – | % |
| Power Supply Rejection Ratio<br>(4.5 V < $V_{CC}$ < 5.5 V, $V_{EE}$ = – 5.2 V)<br>(– 6.0 V < $V_{EE}$ < – 3.0 V, $V_{CC}$ = + 5.0 V) | PSRR | <br>–<br>– | <br>0.1<br>0 | <br>–<br>– | LSB/V |

**ELECTRICAL CHARACTERISTICS – continued**

($0° < T_A < 70°C$, $V_{CC} = 5.0$ V, $V_{EE} = -5.2$ V, $V_{RT} = +1.0$ V, $V_{RB} = -1.0$ V, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **ANALOG INPUTS** (Pin 14) | | | | | |
| Input Current @ $V_{in} = V_{RB}$ (See Figure 5) | $I_{INL}$ | – 100 | 0 | – | μA |
| Input Current @ $V_{in} = V_{RT}$ (See Figure 5) | $I_{INH}$ | – | 60 | 150 | μA |
| Input Capacitance ($V_{RT} - V_{RB} = 2.0$ V, See Figure 4) | $C_{in}$ | – | 36 | – | pF |
| Input Capacitance ($V_{RT} - V_{RB} = 1.0$ V, See Figure 4) | $C_{in}$ | – | 55 | – | pF |
| Bipolar Offset Error | $V_{OS}$ | – | 0.1 | – | LSB |
| **REFERENCE** | | | | | |
| Ladder Resistance ($V_{RT}$ to $V_{RB}$, $T_A = 25°C$) | $R_{ref}$ | 104 | 130 | 156 | Ω |
| Temperature Coefficient | $T_C$ | – | + 0.29 | – | %/°C |
| Ladder Capacitance (Pin 1 open) | $C_{ref}$ | – | 25 | – | pF |
| **ENABLE INPUTS** ($V_{CC} = 5.5$ V) (See Figure 6) | | | | | |
| Input Voltage – High (Pins 19 to 20) | $V_{IHE}$ | 2.0 | – | – | V |
| Input Voltage – Low (Pins 19 to 20) | $V_{ILE}$ | – | – | 0.8 | V |
| Input Current @ 2.7 V | $I_{IHE}$ | – | 0 | 20 | μA |
| Input Current @ 0.4 V @ $\overline{EN}$ ($0 < EN < 5.0$ V) | $I_{IL1}$ | – 400 | – 100 | – | μA |
| Input Current @ 0.4 V @ EN ($\overline{EN} = 0$ V) | $I_{IL2}$ | – 400 | – 100 | – | μA |
| Input Current @ 0.4 V @ EN ($\overline{EN} = 2.0$ V) | $I_{IL3}$ | – 20 | – 2.0 | – | μA |
| Input Clamp Voltage ($I_{IK} = -18$ mA) | $V_{IKE}$ | – 1.5 | – 1.3 | – | V |
| **CLOCK INPUTS** ($V_{CC} = 5.5$ V) | | | | | |
| Input Voltage High | $V_{IHC}$ | 2.0 | – | – | Vdc |
| Input Voltage Low | $V_{ILC}$ | – | – | 0.8 | Vdc |
| Input Current @ 0.4 V (See Figure 7) | $I_{ILC}$ | – 400 | – 80 | – | μA |
| Input Current @ 2.7 V (See Figure 7) | $I_{IHC}$ | – 100 | – 20 | – | μA |
| Input Clamp Voltage ($I_{IK} = -18$ mA) | $V_{IKC}$ | – 1.5 | – 1.3 | – | Vdc |
| **DIGITAL OUTPUTS** | | | | | |
| High Output Voltage ($I_{OH} = -400$ μA, $V_{CC} = 4.5$ V, See Figure 8) | $V_{OH}$ | 2.4 | 3.0 | – | V |
| Low Output Voltage ($I_{OL} = 4.0$ mA, See Figure 9) | $V_{OL}$ | – | 0.35 | 0.4 | V |
| Output Short Circuit Current* ($V_{CC} = 5.5$ V) | $I_{SC}$ | – | 35 | – | mA |
| Output Leakage Current ($0.4 < V_O < 2.4$ V, See Figure 3, $V_{CC} = 5.5$ V, D0 to D7 in 3–State Mode) | $I_{LK}$ | – 50 | – | + 50 | μA |
| Output Capacitance (D0 to D7 in 3–State Mode) | $C_{out}$ | – | 9.0 | – | pF |
| **POWER SUPPLIES** | | | | | |
| $V_{CC(A)}$ Current ($4.5 < V_{CC(A)} < 5.5$ V) (Outputs unloaded) | $I_{CC(A)}$ | 10 | 17 | 25 | mA |
| $V_{CC(D)}$ Current ($4.5 < V_{CC(D)} < 5.5$ V) (Outputs unloaded) | $I_{CC(D)}$ | 50 | 90 | 133 | mA |
| $V_{EE}$ Current ($-6.0 < V_{EE} < -3.0$ V) | $I_{EE}$ | – 14 | – 10 | – 6.0 | mA |
| Power Dissipation ($V_{RT} - V_{RB} = 2.0$ V) (Outputs unloaded) | $P_D$ | – | 618 | 995 | mW |

*Only one output is to be shorted at a time, not to exceed 1 second.

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**TIMING CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = +5.0 V, $V_{EE}$ = −5.2 V, $V_{RT}$ = +1.0 V, $V_{RB}$ = −1.0 V, see System Timing Diagram, Figure 1.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **INPUTS** | | | | | |
| Min Clock Pulse Width – High | $t_{CKH}$ | – | 5.0 | – | ns |
| Min Clock Pulse Width – Low | $t_{CKL}$ | – | 15 | – | ns |
| Max Clock Rise, Fall Time | $t_{R,F}$ | – | 100 | – | ns |
| Clock Frequency | $f_{CLK}$ | 0 | 30 | 25 | MHz |
| **OUTPUTS** | | | | | |
| New Data Valid from Clock Low | $t_{CKDV}$ | – | 19 | – | ns |
| Aperture Delay | $t_{AD}$ | – | 4.0 | – | ns |
| Hold Time | $t_H$ | – | 6.0 | – | ns |
| Data High to 3–State from Enable Low* | $t_{EHZ}$ | – | 27 | – | ns |
| Data Low to 3–State from Enable Low* | $t_{ELZ}$ | – | 18 | – | ns |
| Data High to 3–State from $\overline{\text{Enable}}$ High* | $t_{\overline{E}HZ}$ | – | 32 | – | ns |
| Data Low to 3–State from $\overline{\text{Enable}}$ High* | $t_{\overline{E}LZ}$ | – | 18 | – | ns |
| Valid Data from Enable High (Pin 20 = 0 V)* | $t_{EDV}$ | – | 15 | – | ns |
| Valid Data from $\overline{\text{Enable}}$ Low (Pin 19 = 5.0 V)* | $t_{\overline{E}DV}$ | – | 16 | – | ns |
| Output Transition Time* (10% to 90%) | $t_{tr}$ | – | 8.0 | – | ns |

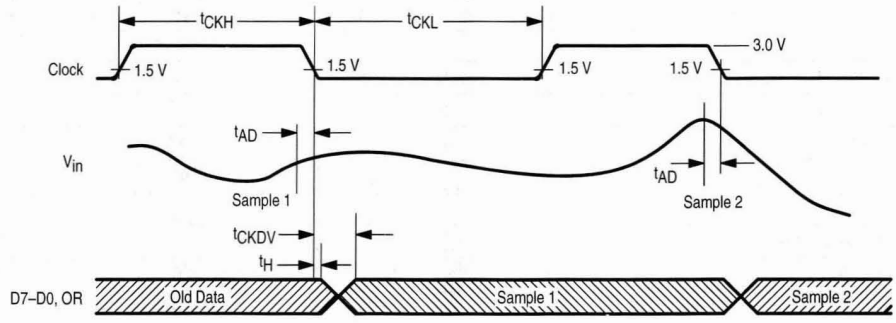
*See Figure 2 for output loading.

**PIN FUNCTION DESCRIPTION**

| Function | Pin | | Description |
|---|---|---|---|
| | P Suffix | DW Suffix | |
| $V_{RM}$ | 1 | 1 | The midpoint of the reference resistor ladder. Bypassing can be done at this point to improve performance at high frequencies. |
| GND | 2, 12<br>16, 22 | 2, 13, 17<br>18, 25, 26 | Digital ground. The pins should be connected directly together, and through a low impedance path to the power supply. |
| OVR | 3 | 3 | Overrange output. Indicates $V_{in}$ is more positive than $V_{RT}$ 1/2 LSB. This output does not have 3–state capability. |
| D7–D0 | 4 to 10, 21 | 4 to 10, 24 | Digital Outputs. D7 (Pin 4) is the MSB. DØ (Pin 21 or 24) is the LSB. LS–TTL compatible with 3–state capability. |
| $V_{CC(D)}$ | 11, 17 | 11, 12<br>19, 20 | Power supply for the digital section. +5.0 V, ±10% required. Reference to digital ground. |
| $V_{EE}$ | 13 | 14 | Negative power supply. Nominally – 5.2 V, it can range from – 3.0 to – 6.0 V, and must be more negative than $V_{RB}$ by > 1.3 V. Reference to analog ground. |
| $V_{in}$ | 14 | 15 | Signal voltage input. This voltage is compared to the reference to generate a digital equivalent. Input impedance is nominally 16 to 33K in parallel with 36 pF. |
| $V_{CC(A)}$ | 15 | 16 | Power supply for the analog section. +5.0 V, ±10% required. Reference to analog ground. |
| CLK | 18 | 21 | Clock input. TTL compatible. |
| EN | 19 | 22 | Enable input. TTL compatible, a logic 1 (and $\overline{\text{EN}}$ at a logic 0) enables the data outputs. A logic 0 puts the outputs in a 3–state mode. |
| $\overline{\text{EN}}$ | 20 | 23 | $\overline{\text{Enable}}$ input. TTL compatible, a logic 0 (and EN at a logic 1) enables the data outputs. A logic 1 puts the outputs in a 3–state mode. |
| $V_{RB}$ | 23 | 27 | The bottom (most negative point) of the internal reference resistor ladder. |
| $V_{RT}$ | 24 | 28 | The top (most positive point) of the internal reference resistor ladder. |

6

**Figure 1. System Timing Diagram**




$t_{CKDV}$ and $t_H$ measured at output levels of 0.8 and 2.4 V.

6

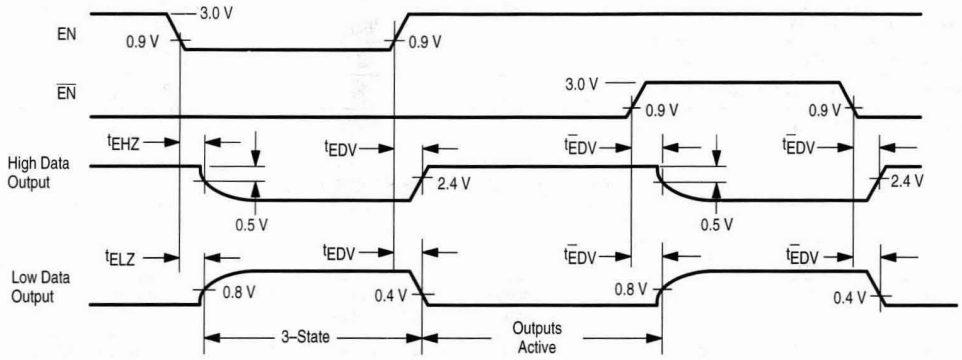
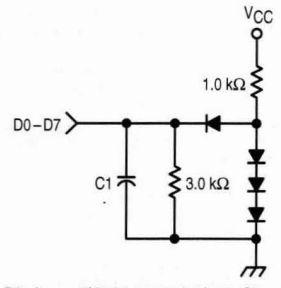



**Figure 2. Data Output Test Circuit**




Diodes = 1N914 or equivalent, C1 ≈ 15 pF

**Figure 3. Output 3–State Leakage Current**

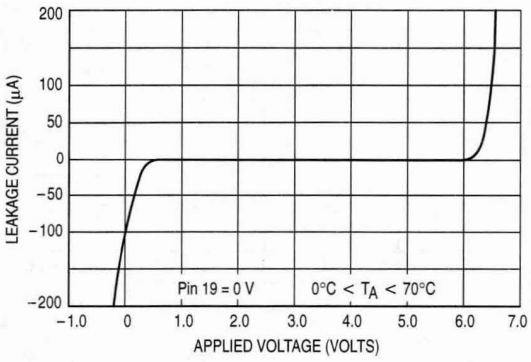


**Figure 4. Input Capacitance @ $V_{in}$ (Pin 14)**

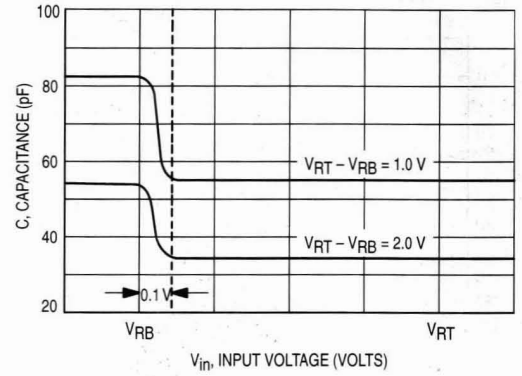



**Figure 5. Input Current @ $V_{in}$ (Pin 14)**

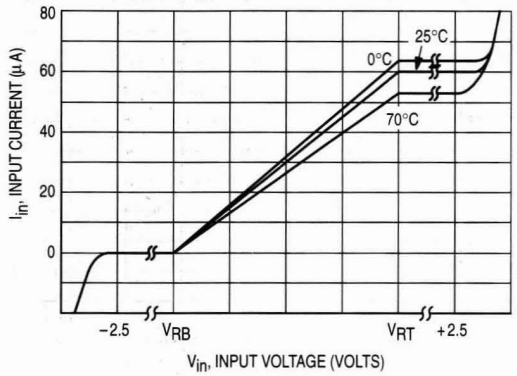



**Figure 6. Input Current @ Enable, $\overline{Enable}$**

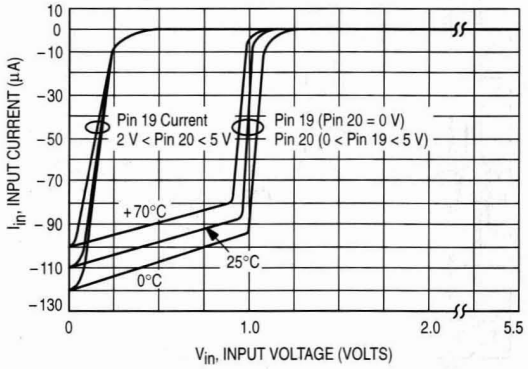



**Figure 7. Clock Input Current**

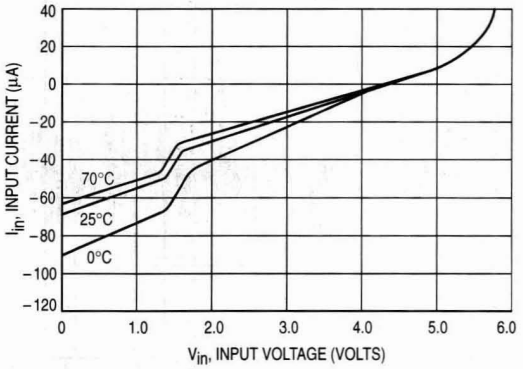



**Figure 8. Output Voltage versus Output Current**

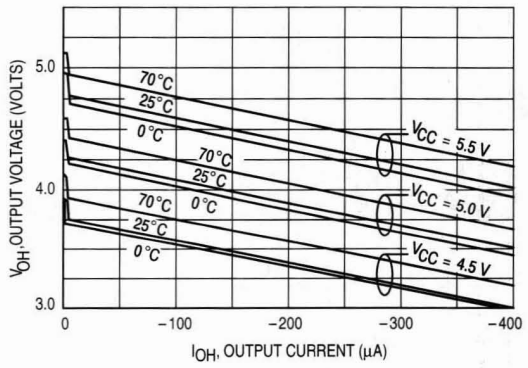



**Figure 9. Output Voltage versus Output Current**

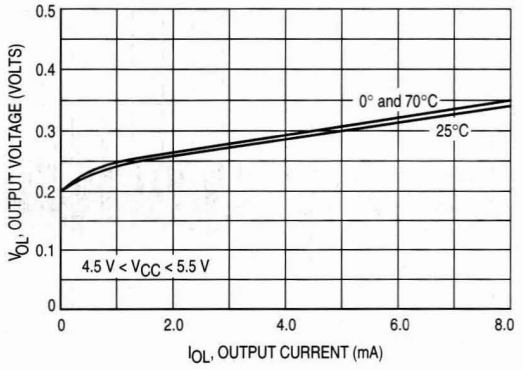



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**Figure 10. Supply Current versus Temperature**

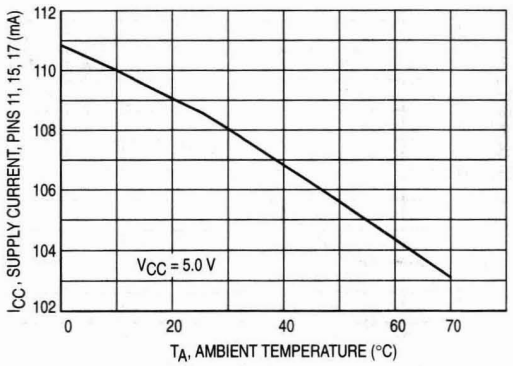


**Figure 11. Supply Current versus Temperature**

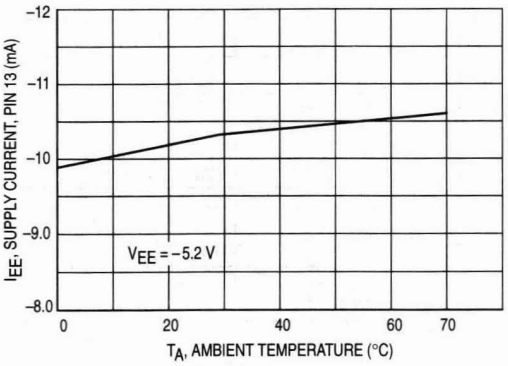


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**Figure 12. Differential Linearity Error**

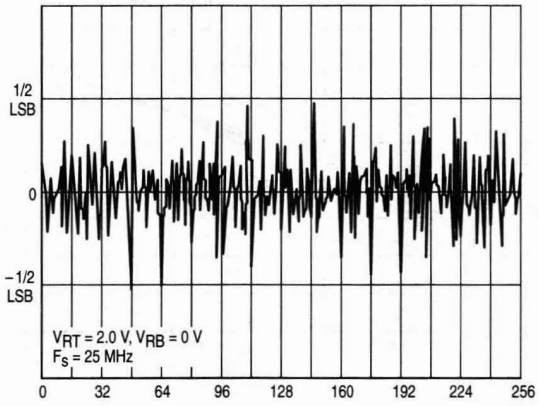



**Figure 13. Integral Linearity Error**

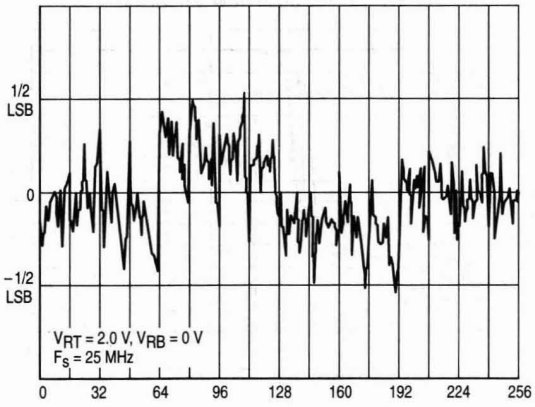



**Figure 14. Differential Linearity Error**

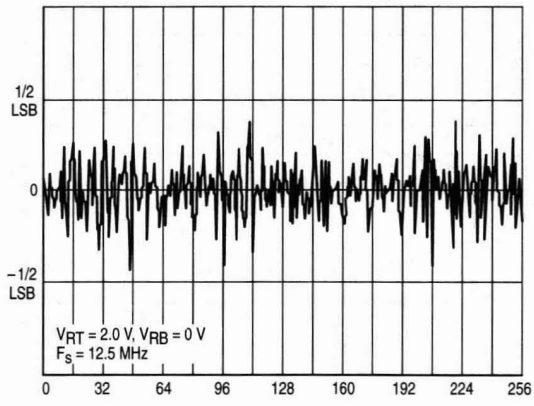
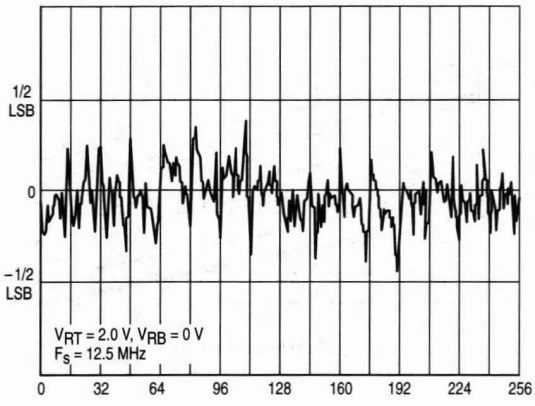



**Figure 15. Integral Linearity Error**



## DESIGN GUIDELINES

### Introduction

The MC10319 is a high speed, 8–bit, parallel ("flash") type analog–to–digital converter containing 256 comparators at the front end. See Figure 17 for a block diagram. The comparators are arranged such that one input of each is referenced to evenly spaced voltages, derived from the reference resistor ladder. The other input of the comparators is connected to the input signal ($V_{in}$). Some of the comparator's differential outputs will be "true," while other comparators will have "not true" outputs, depending on their relative position. Their outputs are then latched, and converted to an 8–bit Grey code by the Differential Latch Array. The Grey code ensures that any input errors due to cross talk, feed–thru, or timing disparities result in glitches at the output of only a few LSBs, rather than the more traditional 1/2 scale and 1/4 scale glitches.

The Grey code is then translated to an 8–bit binary code, and the differential levels are translated to TTL levels before being applied to the output latches. Enable inputs at this final stage permit the TTL outputs (except overrange) to be put into a high impedance (3–state) condition.

## ANALOG SECTION

### Signal Input

The signal voltage to be digitized ($V_{in}$) is applied simultaneously to one input of each of the 256 comparators through Pin 14. The other inputs of the comparators are connected to 256 evenly spaced voltages derived from the reference ladder. The output code depends on the relative position of the input signal and the reference voltages. The comparators have a bandwidth of > 50 MHz, which is more than sufficient for the allowable (Nyquist Theorem) input frequency of 12.5 MHz.

The current into Pin 14 varies linearly from 0 (when $V_{in} = V_{RB}$) to ≈60 μA (when $V_{in} = V_{RT}$). If $V_{in}$ is taken below $V_{RB}$ or above $V_{RT}$, the input current will remain at the value corresponding to $V_{RB}$ and $V_{RT}$ respectively (see Figure 5). However, $V_{in}$ must be maintained within the absolute range of ±2.5 V (with respect to ground) – otherwise excessive currents will result at Pin 14, due to internal clamps.

The input capacitance at Pin 14 is typically 36 pF if [$V_{RT} - V_{RB}$] is 2.0 V, and increases to 55 pF if [$V_{RT} - V_{RB}$] is reduced to 1.0 V (see Figure 4). The capacitance is constant as $V_{in}$ varies from $V_{RT}$ down to ≈0.1 V above $V_{RB}$. Taking $V_{in}$ to $V_{RB}$ will show an increase in the capacitance of ≈50%. If $V_{in}$ is taken above $V_{RT}$, or below $V_{RB}$, the capacitance will stay at the values corresponding to $V_{RT}$ and $V_{RB}$, respectively.

The source impedance of the signal voltage should be maintained below 100 Ω (at the frequencies of interest) in order to avoid sampling errors.

### Reference

The reference resistor ladder is composed of a string of equal value resistors to provide 256 equally spaced voltages for the comparators (see Figure 17 for the actual configuration). The voltage difference between adjacent comparators corresponds to 1 LSB of the input range. The first comparator (closest to $V_{RB}$) is referenced 1/2 LSB above $V_{RB}$, and 256th comparator (for the overrange) is referenced 1/2 LSB below $V_{RT}$. The total resistance of the ladder is nominally 130 Ω, ±20%, requiring 15.4 mA @ 2.0 V, and 7.7 mA @ 1.0 V. There is a nominal warm–up change of ≈ +9.0% in the ladder resistance due to the +0.29%/°C temperature coefficient.

The minimum recommended span [$V_{RT} - V_{RB}$] is 1.0 V. A lower span will allow offsets and nonlinearities to become significant. The maximum recommended span is 2.1 V due to power limitations of the resistor ladder. The span may be anywhere within the range of – 2.1 to + 2.1 V with respect to ground, and $V_{RB}$ must be at least 1.3 V more positive than $V_{EE}$. The reference voltages must be stable and free of noise and spikes, since the accuracy of a conversion is directly related to the quality of the reference.

In most applications, the reference voltages will remain fixed. In applications involving a varying reference for modulation or signal scrambling, the modulating signal may be applied to $V_{RT}$, or $V_{RB}$, or both. The output will vary inversly with the reference signal, introducing a nonlinearity into the transfer function. The addition of the modulating signal and the dc level applied to the reference must be such that the absolute voltage at $V_{RT}$ and $V_{RB}$ is maintained within the values listed in the Recommended Operating Limits. The RMS value of the span must be maintained ≤2.1 V.

$V_{RM}$ (Pin 1) is the midpoint of the resistor ladder, excluding the Overrange comparator. The voltage at $V_{RM}$ is:

$$\frac{V_{RT} + V_{RB}}{2.0} - 1/2 \text{ LSB}$$

In most applications, bypassing this pin to ground (0.1 μF) is sufficient to maintain accuracy. In applications involving very high frequencies, and where linearity is critical, it may be necessary to trim the voltage at the midpoint. A means for accomplishing this is indicated in Figure 18.

### Power Supplies

$V_{CC(A)}$ is the positive power supply for the comparators, and $V_{CC(D)}$ is the positive power supply for the digital portion. Both are to be +5.0 V, ±10%, and the two are to be within 100 mV of each other. There is indirect internal coupling between $V_{CC(D)}$ and $V_{CC(A)}$. If they are powered separately, and one supply fails, there will be current flow through the MC10319 to the failed supply.

$I_{CC(A)}$ is nominally 17 mA, and does not vary with clock frequency or with $V_{in}$. It does vary linearly with $V_{CC(A)}$. $I_{CC(D)}$ is nominally 90 mA, and is independent of clock frequency. It does vary, however, by 6 to 7 mA as $V_{in}$ is changed, with the lowest current occurring when $V_{in} = V_{RT}$. It varies linearly with $V_{CC(D)}$.

$V_{EE}$ is the negative power supply for the comparators, and is to be within the range – 3.0 to – 6.0 V. Additionally, $V_{EE}$ must be at least 1.3 V more negative than $V_{RB}$. $I_{EE}$ is a nominal – 10 mA, and is independent of clock frequency, $V_{in}$, and $V_{EE}$.

For proper operation, the supplies **must** be bypassed **at the IC**. A 10 μF tantalum, in parallel with a 0.1 μF ceramic is recommended for each supply to ground.

## DIGITAL SECTION

### Clock

The Clock input is TTL compatible with a typical frequency range of 0 to 30 MHz. There is no duty cycle limitations, but the minimum low and high times must be adhered to. See Figure 7 for the input current requirements.

The conversion sequence is shown in Figure 19, and is as follows:

- On the rising edge, the data output latches are latched with old data, and the comparator output latches are released to follow the input signal ($V_{in}$).
- During the high time, the comparators track the input signal. The data output latches retain the old data.
- On the falling edge, the comparator outputs are latched with the data immediately prior to this edge. The conversion to digital occurs within the device, and the data output latches are released to indicate the new data within 20 ns.
- During the clock low time, the comparator outputs remain latched, and the data output latches remain transparent.

A summary of the sequence is that data present at $V_{in}$ just prior to the Clock falling edge is digitized and available at the data outputs immediately after that same falling edge.

The comparator output latches provide the circuit with an effective sample–and–hold function, eliminating the need for an external sample–and–hold.

### Enable Inputs

The two Enable inputs are TTL compatible, and are used to change the data outputs (D7–D0) from active to 3–state. This capability allows cascading two MC10319s into a 9–bit configuration, flip–flopping two MC10319s into a 50 MHz configuration, connecting the outputs directly to a data bus, multiplexing multiple converters, etc. See the Applications Information section for more details. For the outputs to be active, Pin 19 must be a Logic "1", and Pin 20 must be a Logic "0". Changing either input will put the outputs into the high impedance mode. The Enable inputs affect **only** the state of the outputs – they do not inhibit a conversion. The input current into Pins 19 and 20 is shown in Figure 6, and the input/output timing is shown in Figure 1 and 20. Leaving either pin open is equivalent to a Logic "1", although good design practice dictates that an input should never be left open.

The Overrange output (Pin 3) is not affected by the Enable inputs as it does not have 3–state capability.

### Outputs

The Data outputs are TTL level outputs with high impedance capability. Pin 4 is the MSB (D7), and Pin 21 is the LSB (D0). The eight outputs are active as long as the Enable inputs are true (Pin 19 = high, Pin 20 = low). The timing of the outputs relative to the Clock input and the Enable inputs is shown in Figures 1 and 20. Figures 8 and 9 indicate the output voltage versus load current, while Figure 3 indicates the leakage current when in the high impedance mode.

The output code is natural binary, depicted in the table below.

The Overrange output (Pin 3) goes high when the input, $V_{in}$, is more positive than $V_{RT}$ – 1/2 LSB. This output is always active – it does not have high impedance capability. Besides being used to indicate an input overrange, it is additionally used for cascading two MC10319s to form a 9–bit A/D converter (see Figure 27).

**Table 1. Output Code**

| Input | $V_{RT}$, $V_{RB}$ (V) | | | Output Code | Overrange |
|---|---|---|---|---|---|
| | 2.048 V, 0 V | + 1.0 V, – 1.0 V | + 1.0 V, 0 V | | |
| > $V_{RT}$ – 1/2 LSB | > 2.044V | > 0.9961 V | > 0.9980 V | $FF_H$ | 1 |
| $V_{RT}$ – 1/2 LSB | 2.044 V | 0.9961 V | 0.9980 V | $FF_H$ | 0 ↔ 1 |
| $V_{RT}$ – 1 LSB | 2.040 V | 0.992 V | 0.9961 V | $FF_H$ | 0 |
| $V_{RT}$ – 1–1/2 LSB | 2.036 V | 0.988 V | 0.9941 V | $FE_H \leftrightarrow FF_H$ | 0 |
| Midpoint | 1.024 V | 0.000 V | 0.5000 V | $80_H$ | 0 |
| $V_{RB}$ + 1/2 LSB | 4.0 mV | – 0.9961 V | 1.95 mV | $00_H \leftrightarrow 01_H$ | 0 |
| < $V_{RB}$ | < 0 V | < – 1.0 V | < 0 V | $00_H$ | 0 |

## APPLICATIONS INFORMATION

### Power Supplies, Grounding

The PC board layout, and the quality of the power supplies and the ground system **at the IC** are very important in order to obtain proper operation. Noise, from any source, coming into the device on $V_{CC}$, $V_{EE}$, or ground can cause an incorrect output code due to interaction with the analog portion of the circuit. At the same time, noise generated within the MC10319 can cause incorrect operation if that noise does not have a clear path to ac ground.

Both the $V_{CC}$ and $V_{EE}$ power supplies must be decoupled to ground **at the IC** (within 1″ max) with a 10 μF tantalum and a 0.1 μF ceramic. Tantalum capacitors are recommended since electrolytic capacitors simply have too much inductance at the frequencies of interest. The quality of the $V_{CC}$ and $V_{EE}$ supplies should then be checked at the IC with a high frequency scope. Noise spikes (always present when digital circuits are present) can easily exceed 400 mV peak, and if they get into the analog portion of the IC, the operation can be disrupted. Noise can be reduced by inserting resistors and/or inductors between the supplies and the IC.

If switching power supplies are used, there will usually be spikes of 0.5 V or greater at frequencies of 50 to 200 kHz. These spikes are generally more difficult to reduce because of their greater energy content. In extreme cases, 3–terminal regulators (MC78L05ACP, MC7905.2CT), with appropriate high frequency filtering, should be used and dedicated to the MC10319.

The ripple content of the supplies should not allow their magnitude to exceed the values in the Recommended Operating Limits table.

The PC board tracks supplying $V_{CC}$ and $V_{EE}$ to the MC10319 should preferably not be at the tail end of the bus distribution, after passing through a maze of digital circuitry. The MC10319 should be close to the power supply, or the connector where the supply voltages enter the board. If the $V_{CC}$ and $V_{EE}$ lines are supplying considerable current to other parts of the boards, then it is preferable to have dedicated lines from the supply or connector directly to the MC10319.

The four ground pins (2, 12, 16, and 22) must be connected directly together. Any long path between them can cause stability problems due to the inductance (at 25 MHz) of the PC tracks. The ground return for the signal source must be noise free.

### Reference Voltage Circuits

Since the accuracy of the conversion is directly related to the quality of the references, it is imperative that accurate and stable voltages be provided to $V_{RT}$ and $V_{RB}$. If the reference span is 2.0 V, then 1/2 LSB is only 3.9 mV, and it is desireable that $V_{RT}$ and $V_{RB}$ be accurate to within this amount, and furthermore, that they do not drift more than this amount once set. Over the temperature range of 0° to 70°C, a maximum temperature coefficient of 28 ppm/°C is required.

The voltage supplies used for digital circuits should preferably **not** be used as a source for generating $V_{RT}$ and $V_{RB}$, due to the noise spikes (50 to 400 mV) present on the supplies and on their ground lines. Generally ±15 V, or ±12 V, are available for analog circuits, and are usually clean compared to supplies used for digital circuits, although ripple may be present in varying amounts. Ripple is easier to filter out than spikes, however, and so these supplies are preferred.

Figure 21 depicts a circuit which can provide an extremely stable voltage to $V_{RT}$ **at the current required** (the maximum reference current is 19.2 mA @ 2.0 V). The MC1403 series of reference sources has very low temperature coefficients, good noise rejection, and a high initial accuracy, allowing the circuit to be built without an adjustment pot if the $V_{RT}$ voltage is to remain fixed at one value. Using 0.1% wirewound resistors for the divider provides sufficient accuracy and stability in many cases. Alternately, resistor networks provide high ratio accuracies, and close temperature tracking. If the application requires $V_{RT}$ to be changed periodically, the two resistors can be replaced with a 20 turn, cermet potentiometer. Wirewound potentiometers should not be used for this type of application since the pot's slider jumps from winding to winding, and an exact setting can be difficult to obtain. Cermet pots allow for a smooth continuous adjustment.

In Figure 21, R1 reduces the power dissipation in the transistor, and can be carbon composition. The 0.1 μF capacitor in the feedback path provides stability in the unity gain configuration. Recommended op amps are: LM358, MC34001 series, LM308A, LM324, and LM11C. Offset drift is the key parameter to consider in choosing an op amp, and the LM308A has the lowest drift of those mentioned. Bypass capacitors are not shown in Figure 21, but should always be provided at the input to the 2.5 V reference, and at the power supply pins of the op amp.

Figure 22 shows a simpler and more economical circuit, using the LM317LZ regulator, but with lower initial accuracy and temperature stability. The op amp/current booster is not needed since the LM317LZ can supply the current directly. In a well controlled environment, this circuit will suffice for many applications. Because of the lower initial accuracy, an adjustment pot is a necessity.

Figure 23 shows two circuits for providing the voltage to $V_{RB}$. The circuits are similar to those of Figures 21 and 22, and have similar accuracy and stability. The output transistor is a PNP in this case since the circuit must sink the reference current.

## VIDEO APPLICATIONS

The MC10319 is suitable for digitizing video signals directly without signal conditioning, although the standard 1.0 $V_{pp}$ video signal can be amplified to a 2.0 $V_{pp}$ signal for slightly better accuracy. Figure 24 shows the input (top trace) and reconstructed output of a standard NTSC test signal, sampled at 25 MSPS, consisting of a sync pulse, 3.58 MHz color burst, a 3.58 MHz signal in a $Sin^2x$ envelope, a pulse, a white level signal, and a black level signal. Figure 25 shows a $Sin^2x$ pulse that has been digitized and reconstructed at 25 MSPS. The width of the pulse is ≈450 ns at the base. Figure 26 shows an application circuit for digitizing video.

### 9–Bit A/D Converter

Figure 27 shows how two MC10319s can be connected to form a 9–bit converter. In this configuration, the outputs (D7 to D0) of the two 8–bit converters are paralleled. The outputs of one device are active, while the outputs of the other are in the 3–state mode. The selection is made by the Overrange output of the lower MC10319, which controls Enable inputs on the two devices. Additionally, this output provides the 9th bit.

The reference ladders are connected in series, providing the 512 steps required for 9 bits. The input voltage range is determined by $V_{RT}$ of the upper MC10319, and $V_{RB}$ of the lower device. A minimum of 1.0 volt is required across each converter. The 500 Ω pot (20 turn cermet) allows for adjustment of the midpoint since the reference resistors of the two MC10319s may not be identical in value. Without the adjustment, a non–equal voltage division would occur, resulting in a nonlinear conversion. If the references are to be symmetrical about ground (e.g., ± 1.0 V), the adjustment can be eliminated, and the midpoint connected to ground. The use of latches on the outputs is optional, depending on the application.

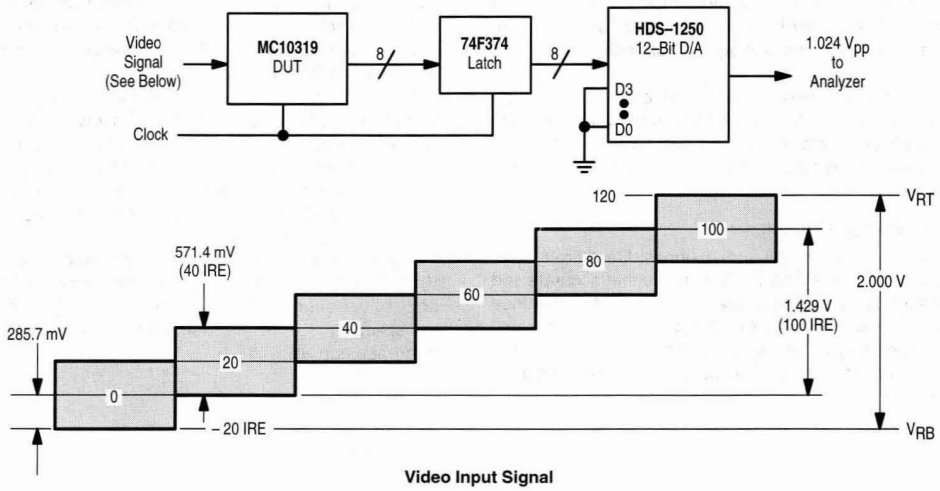
### 50 MHz, 8–Bit A/D Converter

Figure 28 shows how two MC10319s can be connected together in a flip–flop arrangement in order to have an effective conversion speed of 50 MHz. The 74F74 D–type flip–flop provides a 25 MHz clock to each converter, and at the same time, controls the Enables so as to alternately enable and disable the outputs. The Overranges do not have 3–state capability, and so cannot be paralleled. Instead they are OR'd together. The use of latches is optional, and depends on the application. Data should be latched, or written to RAM (in a DMA operation), on the high–to–low transition of the 50 MHz clock.

### Negative Voltage Regulator

In the cases where a negative power supply is not available (neither the – 3.0 to – 6.0 V, nor a higher negative voltage from which to derive it), the circuit of Figure 29 can be used to generate – 5.0 V from the + 5.0 V supply. The PC board space required is small (≈ 2.0 $in^2$), and it can be located physically close to the MC10319. The MC34063A is a switching regulator, and in Figure 29 is configured in an inverting mode of operation. The regulator operating specifications are also given.

**Figure 16. Differential Phase and Gain Test**




**Video Input Signal**

1. Input waveform: 571.4 $mV_{pp}$, sine wave @ 3.579545 MHz, dc levels as shown above.
2. MC10319 clock at 14.31818 MHz (4x) asynchronous to input.
3. Differential gain: peak–to–peak output @ each IRE level compared to that at 0 IRE.
4. Differential phase: Phase @ each IRE level compared to that @ 0 IRE.

**Figure 17. Representative Block Diagram**

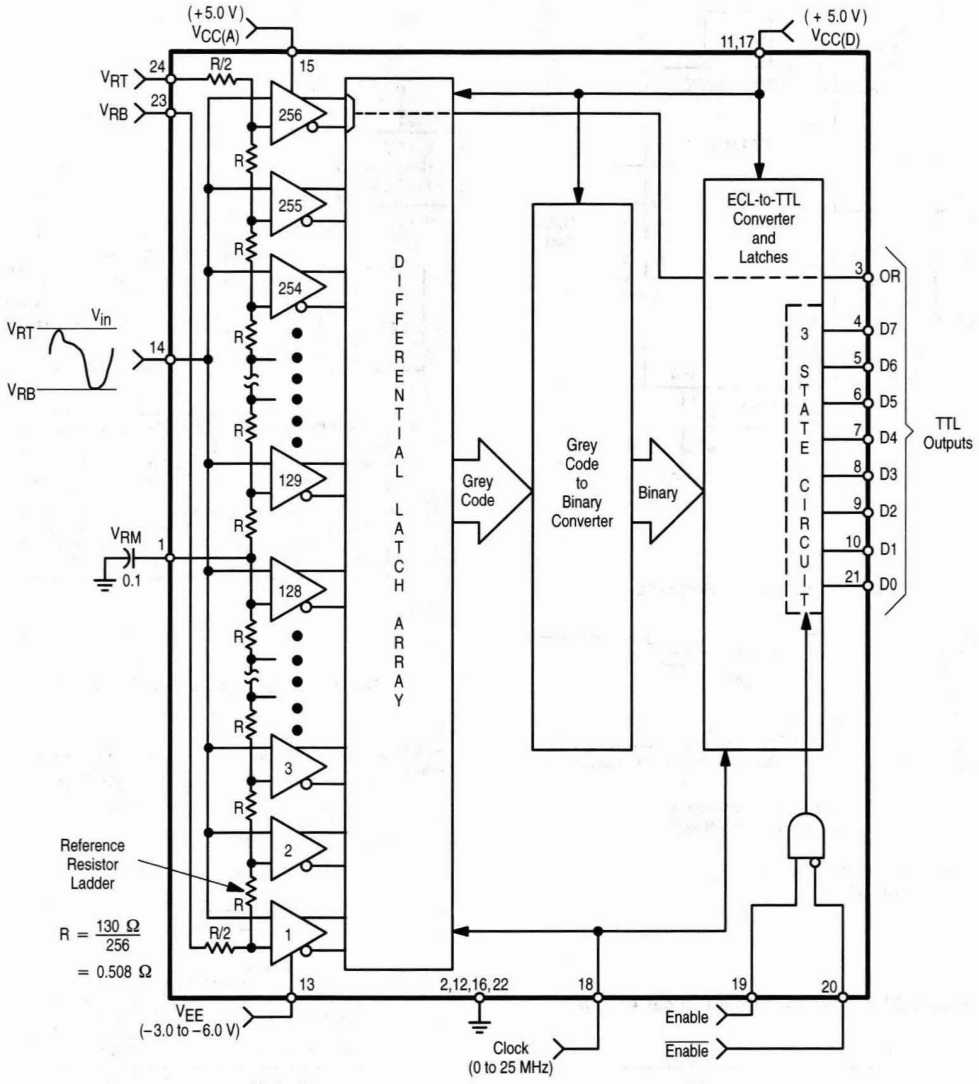



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**Figure 18. Adjusting $V_{RM}$ for Improved Linearity**

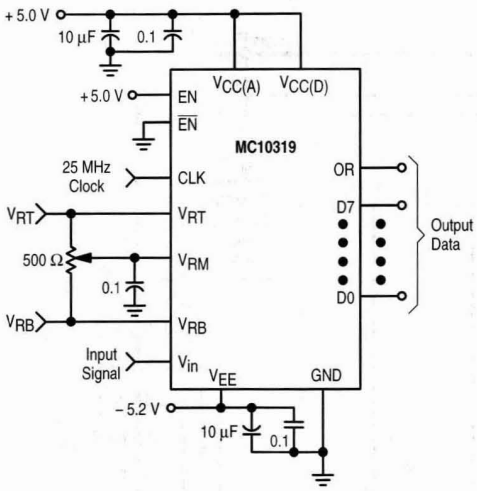



**Figure 19. Conversion Sequence**

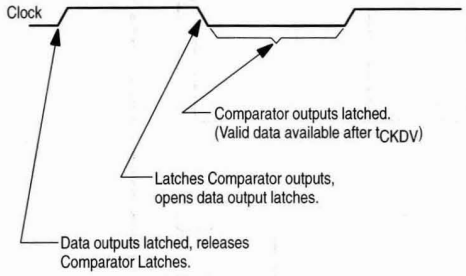
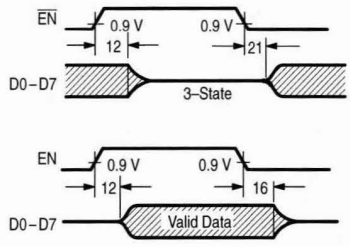


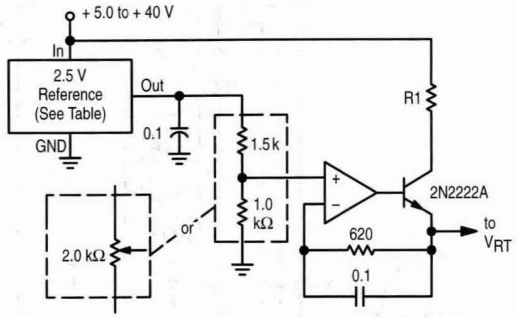

**Figure 20. Enable to Output Critical Timing**




Timing @ D7 to D0 measured where waveform starts to change.
Indicated time values are typical @ 25°C, and are in ns.

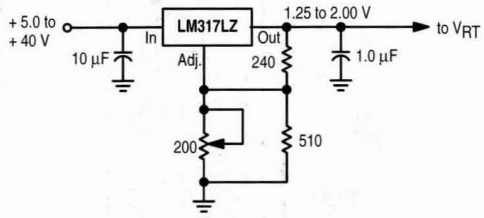
**Figure 21. Precision $V_{RT}$ Voltage Source**

R1 = 100 Ω for +5.0 V
620 Ω for +15 V



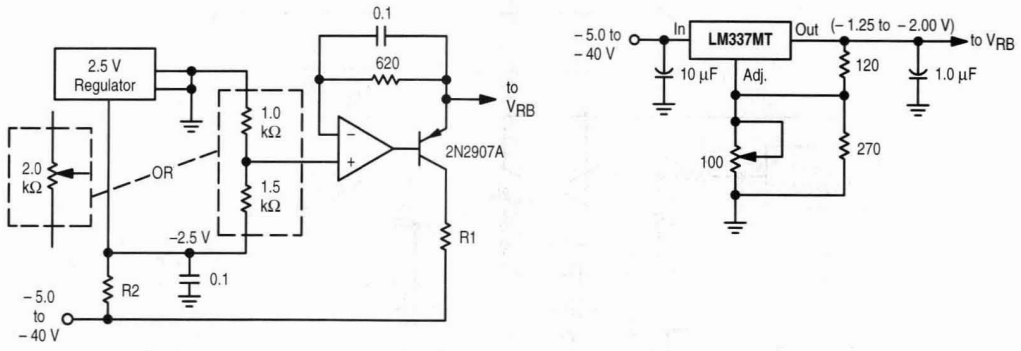

| 2.5 V References | MC1403 | MC1403A |
|---|---|---|
| Line Regulation | 0.5 mV | 0.5 mV |
| $T_C$ (ppm/°C) max | 40 | 25 |
| $\Delta V_{out}$ for 0 to +70°C | 7.0 mV | 4.4 mV |
| Initial Accuracy | ± 1% | ± 1% |

**Figure 22. Voltage Source for $V_{RT}$ Pin**




| LM317LZ | |
|---|---|
| Line Regulation | 1.0 mV |
| $T_C$ (ppm/°C) max | 60 |
| $\Delta V_{out}$ for 0 to +70°C | 8.4 mV |
| Initial Accuracy | ± 4% |

**Figure 23. Voltage Sources for $V_{RB}$ Pin**




R1 = 100 Ω for –5.0 V
= 620 Ω for –15 V

R2 = 620 Ω for –5.0 V
= 3.0 kΩ for –15 V

| 2.5 V Reference | LM337MT |
|---|---|
| Line Regulation | 1.0 mV |
| $T_C$ (ppm/°C) max | 48 |
| $\Delta V_{out}$ for 0 to +70°C | 6.7 mV |
| Initial Accuracy | ±4% |

6

**Figure 24. Composite Video Waveform**

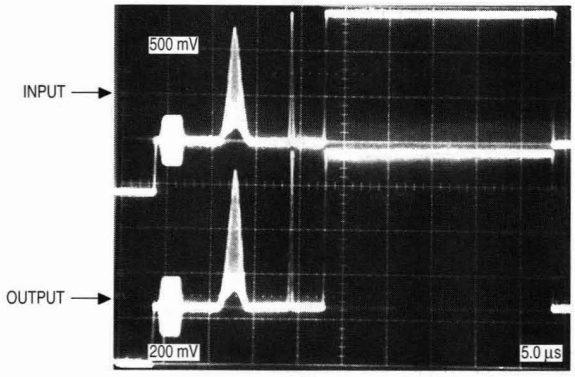



**Figure 25. $SIN^2$ x Waveform**

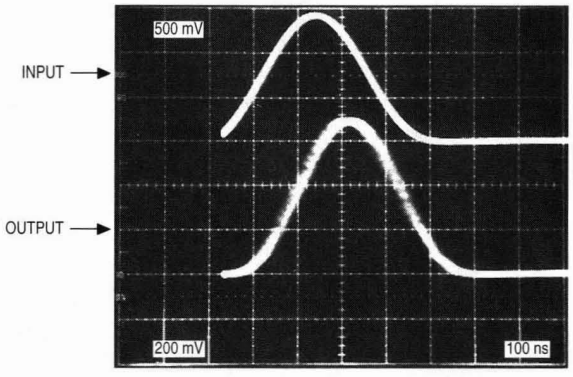
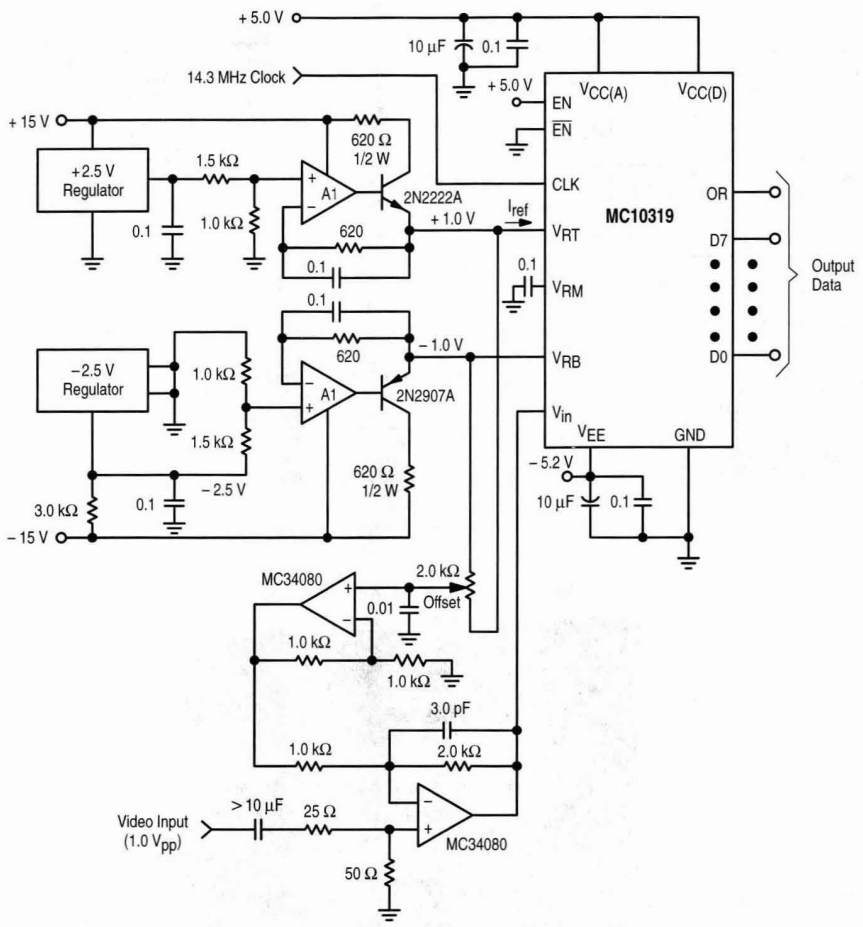


**Figure 26. Application Circuit for Digitizing Video**




**NOTES:** 1) MC34080's powered from ± 15 V supplies. MC34083 (Dual) may be used.
2) Bypass capacitors required at power supply pins of **all** ICs.
3) Ground plane required over all parts of circuit board.
4) Care in layout around MC34080's necessary for good frequency response.
5) A1 = MC34002.

**Figure 27. 9–Bit A/D Converter**

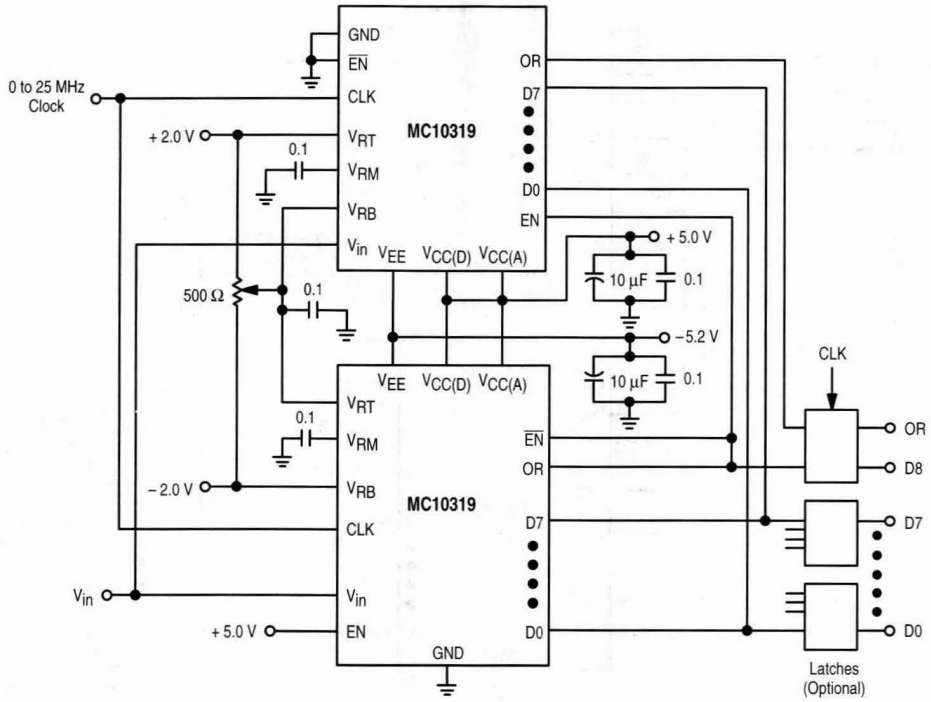


**Figure 28. 50 MHz 8–Bit A/D Converter**

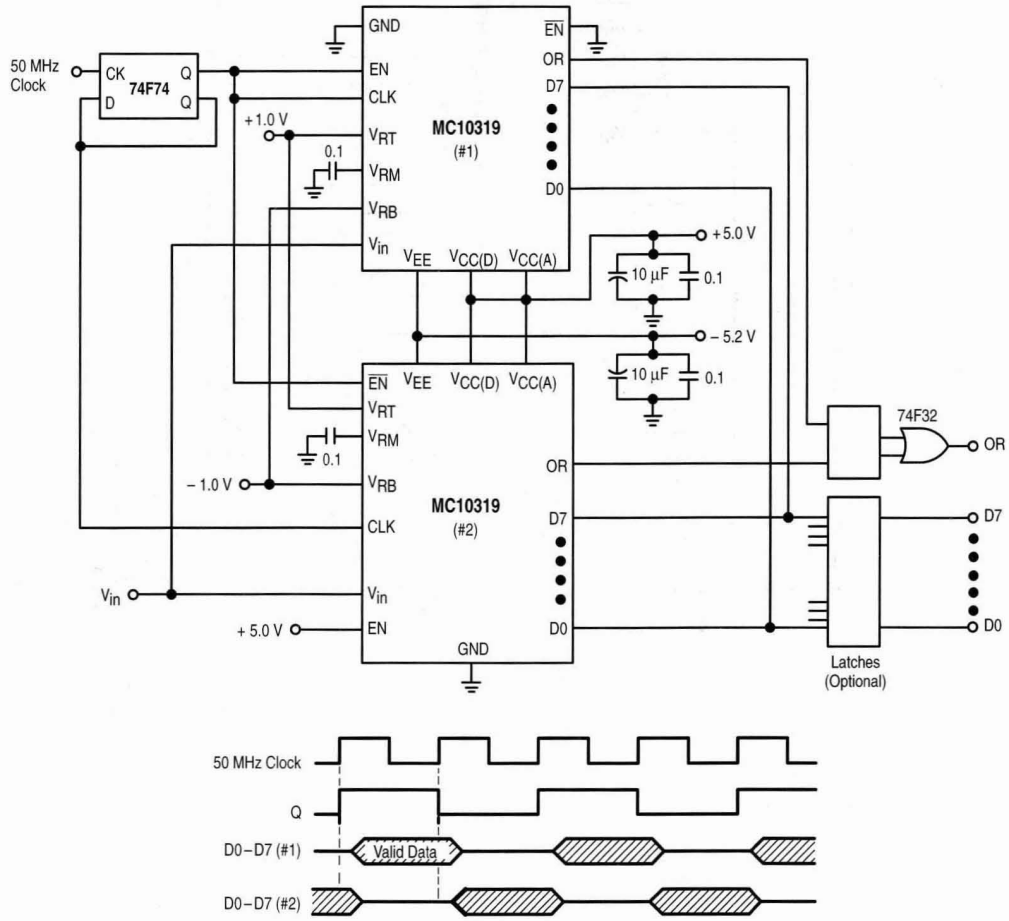
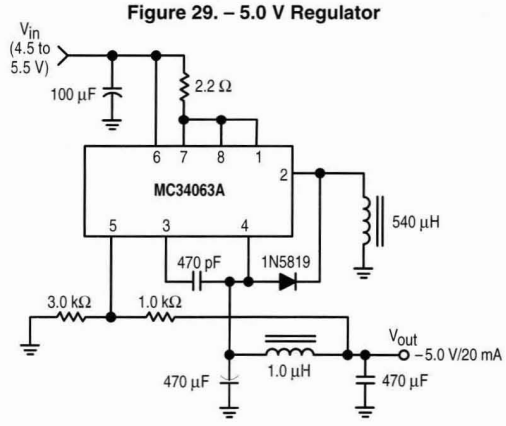



**Figure 29. – 5.0 V Regulator**




| Test | Conditions | Results |
|---|---|---|
| Line Regulation | 4.5 V < $V_{in}$ < 5.5 V, $I_{out}$ = 10 mA | 0.16% |
| Load Regulation | $V_{in}$ = 5.0 V, 8.0 mA < $I_{out}$ < 20 mA | 0.4% |
| Output Ripple | $V_{in}$ = 5.0 V, $I_{out}$ = 20 mA | 2.0 $mV_{pp}$ |
| Short Circuit $I_{out}$ | $V_{in}$ = 5.0 V, R1 = 0.1 Ω | 140 mA |
| Efficiency | $V_{in}$ = 5.0 V, $I_{out}$ = 50 mA | 52% |

## GLOSSARY

**Aperture Delay** – The time difference between the sampling signal (typically a clock edge) and the actual analog signal converted. The actual signal converted may occur before or after the sampling signal, depending on the internal configuration of the converter.

**Bipolar Input** – A mode of operation whereby the analog input (of an A/D), or output (of a DAC), includes both negative and positive values. Examples are – 1.0 to + 1.0 V, – 5.0 to + 5.0 V, – 2.0 to + 8.0 V, etc.

**Bipolar Offset Error** – The difference between the actual and ideal locations of the $00_H$ to $01_H$ transition, where the ideal location is 1/2 LSB above the most negative reference voltage.

**Bipolar Zero Error** – The error (usually expressed in LSBs) of the input voltage location (of an A/D) of the $80_H$ to $81_H$ transition. The ideal location is 1/2 LSB above zero volts in the case of an A/D setup for a symmetrical bipolar input (e.g., – 1.0 to + 1.0 V).

**Differential Nonlinearity** – The maximum deviation in the actual step size (one transition level to another) from the ideal step size. The ideal step size is defined as the Full Scale Range divided by $2^n$ (n = number of bits). This error must be within ± 1 LSB for proper operation.

**ECL** – Emitter coupled logic.

**Full Scale Range (Actual)** – The difference between the actual minimum and maximum end points of the analog input (of an A/D).

**Full Scale Range (Ideal)** – The difference between the actual minimum and maximum end points of the analog input (of an A/D), plus one LSB.

**Gain Error** – The difference between the actual and expected gain (end point to end point), with respect to the reference, of a data converter. The gain error is usually expressed in LSBs.

**Grey Code** – Also known as *reflected binary code*, it is a digital code such that each code differs from adjacent codes by only one bit. Since more than one bit is never changed at each transition, race condition errors are eliminated.

**Integral Nonlinearity** – The maximum error of an A/D, or DAC, transfer function from the ideal straight line connecting the analog end points. This parameter is sensitive to dynamics, and test conditions must be specified in order to be meaningful. This parameter is the best overall indicator of the device's performance.

**Line Regulation** – The ability of a voltage regulator to maintain a certain output voltage as the input to the regulator is varied. The error is typically expressed as a percent of the nominal output voltage.

**Load Regulation** – The ability of a voltage regulator to maintain a certain output voltage as the load current is varied. The error is typically expressed as a percent of the nominal output voltage.

**LSB** – Least Significant Bit. It is the lowest order bit of a binary code.

**Monotonicity** – The characteristic of the transfer function whereby increasing the input code (of a DAC), or the input signal (of an A/D), results in the output never decreasing.

**MSB** – Most Significant Bit. It is the highest order bit of a binary code.

**Natural Binary Code** – A binary code defined by:

$$N = A_n2^n + \ldots + A_32^3 + A_22^2 + A_12^1 + A_02^0$$

where each "A" coefficient has a value of 1 or 0. Typically, all zeroes correspond to a zero input voltage of an A/D, and all ones correspond to the most positive input voltage.

**Nyquist Theorem** – See Sampling Theorem.

**Offset Binary Code** – Applicable only to bipolar input (or output) data converters, it is the same as Natural Binary, except that all zeros correspond to the most negative input voltage (of an A/D), while all ones correspond to the most positive input.

**Power Supply Sensitivity** – The change in a data converter's performance with changes in the power supply voltage(s). This parameter is usually expressed in percent of full scale versus ΔV.

**Quantitization Error** – Also known as *digitization error* or uncertainty. It is the inherent error involved in digitizing an analog signal due to the finite number of steps at the digital output versus the infinite number of values at the analog input. This error is a minimum of ± 1/2 LSB.

**Resolution** – The smallest change which can be discerned by an A/D converter, or produced by a DAC. It is usually expressed as the number of bits (n), where the converter has $2^n$ possible states.

**Sampling Theorem** – Also known as the *Nyquist Theorem*. It states that the sampling frequency of an A/D must be no less that 2x the highest frequency (of interest) of the analog signal to be digitized in order to preserve the information of that analog signal.

**Unipolar Input** – A mode of operation whereby the analog input range (of an A/D), or output range (of a DAC), includes values of a signal polarity. Examples are 0 to + 2.0 V, 0 to – 5.0 V, 2.0 to 8.0 V, etc.

**Unipolar Offset Error** – The difference between the actual and ideal locations of the $00_H$ to $01_H$ transition, where the ideal location is 1/2 LSB above the most negative input voltage.

# Interface Circuits

## In Brief . . .

Described in this section is Motorola's line of interface circuits, which provide the means for interfacing with microprocessor or digital systems and the external world, or to other systems.

Also included are devices which allow a microprocessor to communicate with its own array of memory and peripheral I/O circuits.

The line drivers, receivers, and transceivers permit communication between systems over cables of several thousand feet in length, and at data rates of up to several megahertz. The common EIA data transmission standards, several European standards, and IEEE–488 are addressed by these devices.

The peripheral drivers are designed to handle high current loads such as relay coils, lamps, stepper motors, and others. Input levels to these drivers can be TTL, CMOS, high voltage MOS, or other user defined levels. The display drivers are designed for LCD or LED displays, and provide various forms of decoding.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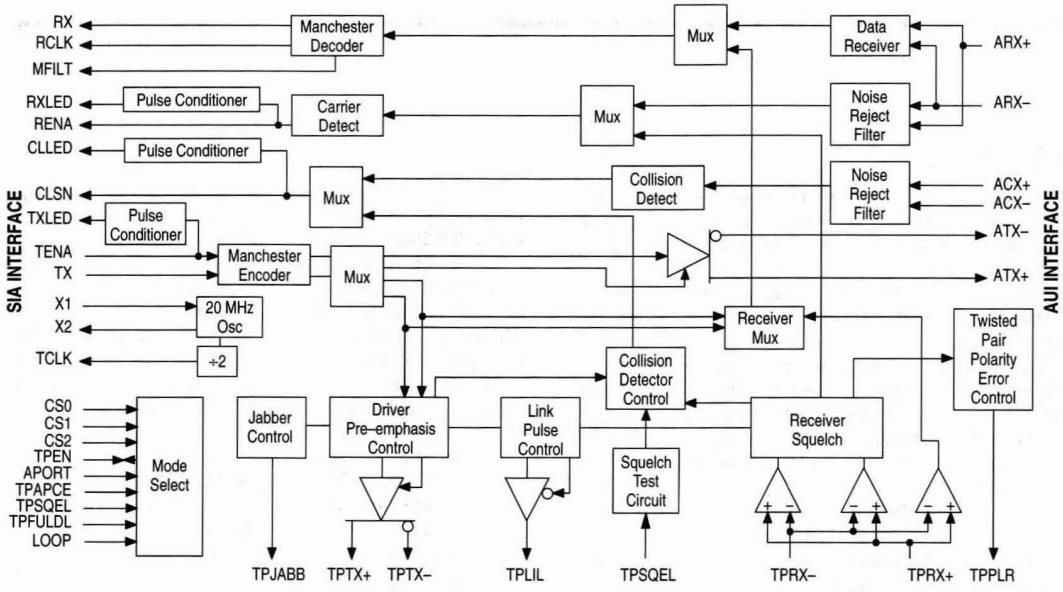
# Enhanced Ethernet Transceiver

**MC68160FB**

$T_A$ = 0° to +70°C, Case 848D

The MC68160 Enhanced Ethernet Interface Circuit is a BiCMOS device which supports both IEEE 802.3 Access Unit Interface (AUI) and 10BASE–T Twisted Pair (TP) Interface media connections through external isolation transformers. It encodes NRZ data to Manchester data and supplies the signals which are required for data communication via 10BASE–T or AUI interfaces. The MC68160 gluelessly interfaces to the Ethernet controller contained in the MC68360 Quad Integrated Communications Controller (QUICC) device. The MC68160 also interfaces easily to most other industry–standard IEEE 802.3 LAN controllers. Prior to twisted pair data reception, Smart Squelch circuitry qualifies input signals for correct amplitude, pulse width, and sequence requirements.

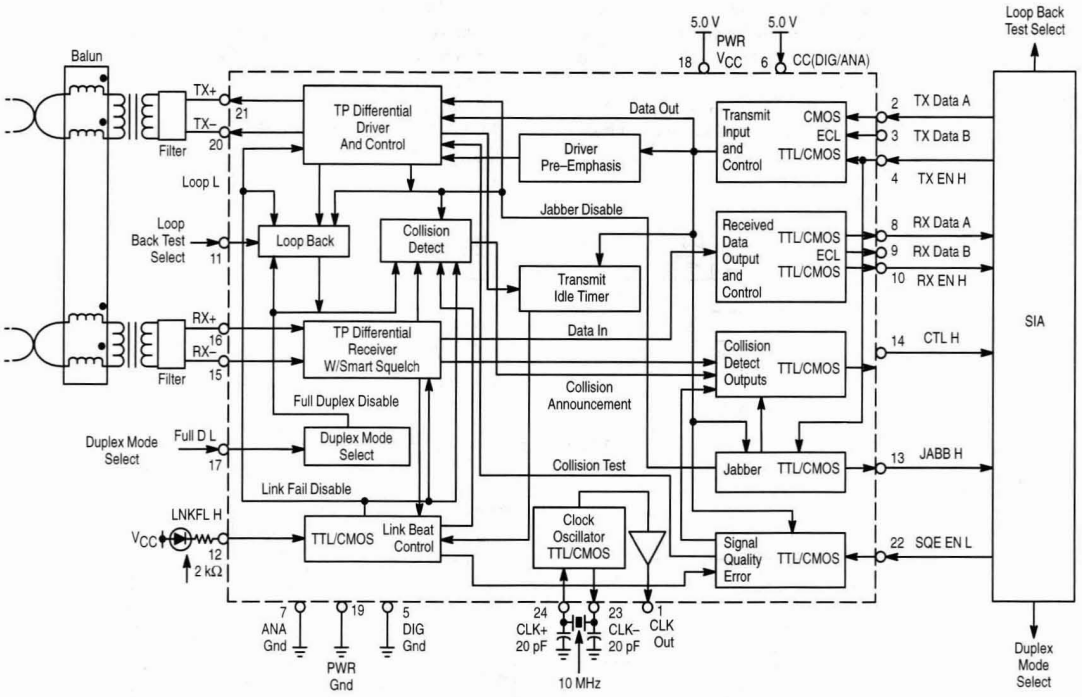


# ISO 8802–3[IEEE 802.3] 10BASE–T Transceiver

**MC34055DW**

$T_A$ = 0° to +70°C, Case 751E

The Motorola 10BASE–T transceiver, designed to comply with the ISO 8802–3[IEEE 802.3] 10BASE–T specification, will support a Medium Dependent Interface (MDI) in an embedded Media Attachment Unit (MAU). The interface supporting the Data Terminal Equipment (DTE) is TTL, CMOS, and raised ECL compatible, and the interface to the Twisted Pair (TP) media is supported through standard 10BASE–T filters and transformers. Differential data intended for the TP media is provided a 50 ns pre–emphasis and data at the TP receiver, is screened by Smart Squelch circuitry for specific threshold, pulse width, and sequence requirements.



# Hex EIA–485 Transceiver with Three–State Outputs

**MC34058/59FTA**

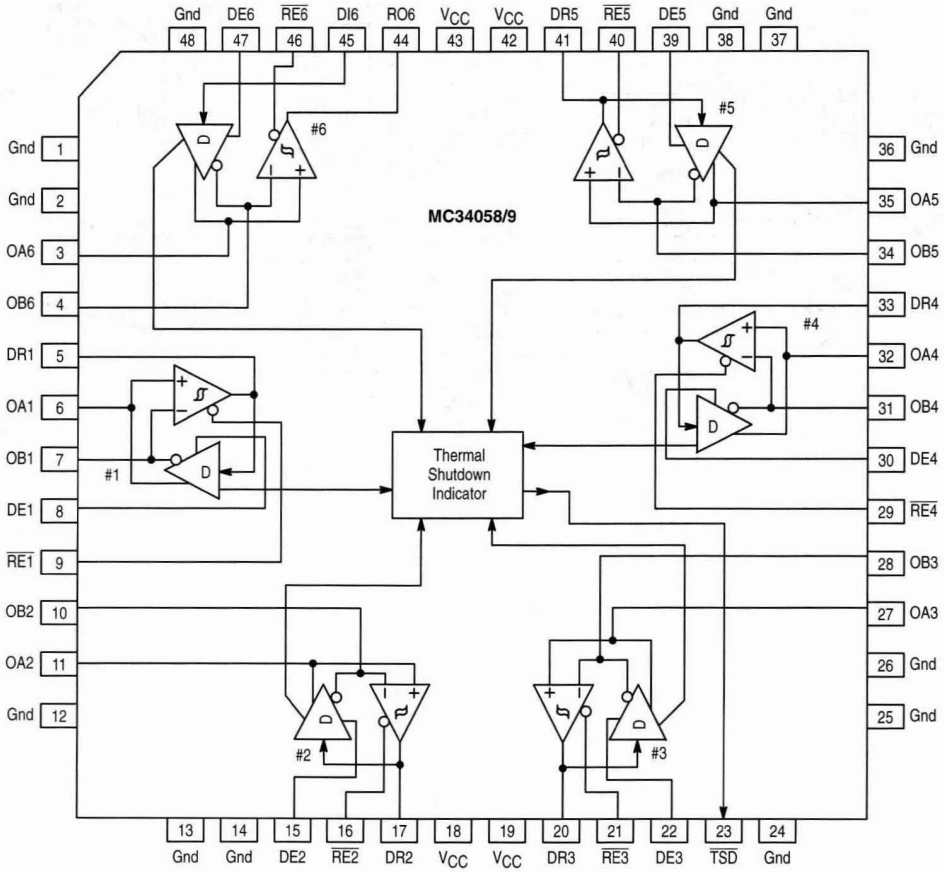
$T_A$ = 0° to +70°C, Case 932

The Motorola MC34058/9 Hex Transceiver is composed of six driver/receiver combinations designed to comply with the EIA–485 standard. Features include three–state outputs, thermal shutdown for each driver, and current limiting in both directions. This device also complies with EIA–422 and CCITT Recommendations V.11 and X.27.

The devices are optimized for balanced multipoint bus transmission at rates to 20 MBPS (MC34059). The driver outputs/receiver inputs feature a wide common mode voltage range, allowing for their use in noisy environments. The current limit and thermal shutdown features protect the devices from line fault conditions.

The MC34058/9 is available in a space saving 7.0 mm 48 lead surface mount quad package designed for optimal heat dissipation.

- Meets EIA–485 Standard for Party Line Operation
- Meets EIA–422A and CCITT Recommendations V.11 and X.27
- Operating Ambient Temperature: 0°C to +70°C
- Common Mode Driver Output/Receiver Input Range: –7.0 to +12 V
- Positive and Negative Current Limiting
- Transmission Rates to 14 MBPS (MC34058) and 20 MBPS (MC34059)
- Driver Thermal Shutdown at 150°C Junction Temperature
- Thermal Shutdown Active Low Output
- Single +5.0 V Supply, ±10%
- Low Supply Current
- Compact 7.0 mm 48 Lead TQFP Plastic Package
- Skew Specified for MC34059



# 5.0 V, 200 M–Bit/Sec PR–IV Hard Disk Drive Read Channel

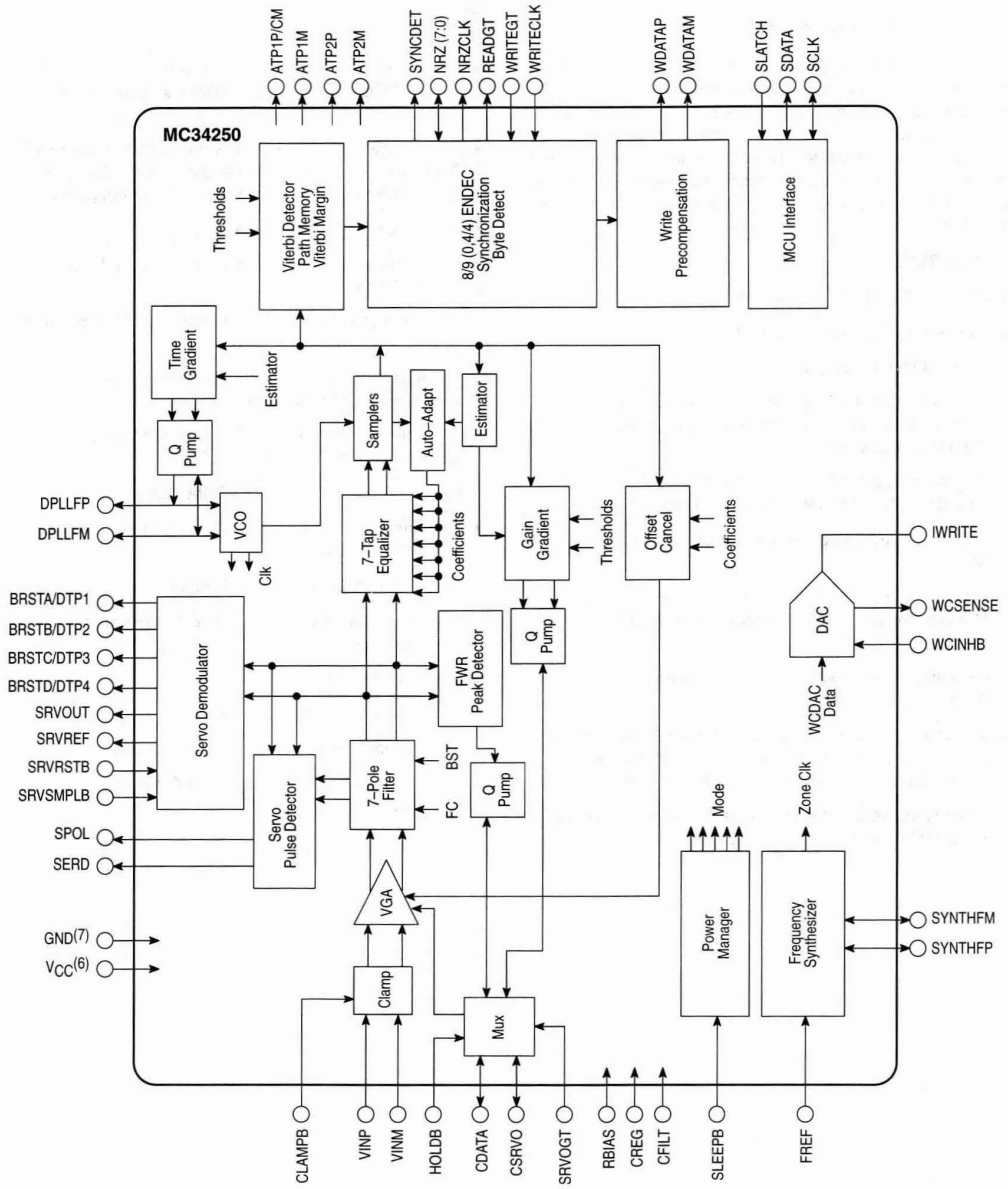
**MC34250FTA**

$T_A$ = 0° to +70°C, Case 840F

The Motorola MC34250 is a fully integrated partial response maximum likelihood disk drive read/write channel for use in zoned recording applications. This device integrates the AGC, active filter, 7 tap equalizer, Viterbi detector, frequency synthesizer, servo demodulator, 8/9 rate (0,4/4) Encoder/Decoder with write precompensation and power management in a single 64 pin 10 mm x 10 mm TQFP package.

## FEATURES:

- 50 to 200 MBPS Programmable Data Rate
- 800 mW at 200 MBPS and 5.0 V
- Channel Monitor Output
- Programmable AGC Charge Pump Currents with Different Values for Data and Servo Envelope Modes and Gain Gradient Mode
- Programmable AGC Peak Detector Droop Currents with Different Values for Data and Servo Envelope Modes
- Separate AGC Charge Pump Outputs for Data and Servo Modes
- Programmable Dual Threshold Qualifier or Hysteresis Comparator Type Pulse Detector for Servo Data Detection.
- ERD and Polarity Outputs for Servo Timing and Raw Encoded Data
- Integrated 7 pole 0.05° Equiripple Linear Phase Filter with Programmable Bandwidth from 5.0 MHz to 80 MHz and Different Values for Both Data and Servo Modes
- Programmable Symmetrical Boost from 0 to 10 dB and Different Values for Data and Servo Modes
- Programmable Asymmetrical Boost of Up to ±40% of Nominal Filter Group Delay in Both Data and Servo Modes
- 7 Tap Continuous Time Transversal Equalizer with 8 Bit Programmable Tap Weights and Integrated Decision Directed Sign–Sign Least Mean Squared Adaptation
- Internal Offset Cancellation Loops
- Fast Acquisition Data Phase Locked Loop with Zero Phase Restart
- Programmable Data Phase Locked Loop Charge Pump Current
- Integrated Soft Decision Viterbi Detectors with Programmable Merge References
- Integrated 8/9 Rate (0,4/4) Encoder and Decoder with Code Scrambler and Descrambler
- Programmable 2/4/8 Bit NRZ Data Interface
- Programmable Write Precompensation Delays Locked to the Frequency Synthesizer
- Differential PECL Write Data Outputs
- External Write Data Path for DC Erase or Other Non–Encoded Data
- Integrated Write Current DAC
- Programmable Power Management
- Bi–Directional Serial Microprocessor Interface
- Various Test Modes Controlled Via the Serial Microprocessor Interface


MC34250
ATP1P/CM
ATP1M
ATP2P
ATP2M
SYNCDET
NRZ (7:0)
NRZCLK
READGT
WRITEGT
WRITECLK
WDATAP
WDATAM
SLATCH
SDATA
SCLK
Thresholds
Viterbi Detector
Path Memory
Viterbi Margin
8/9 (0,4/4) ENDEC
Synchronization
Byte Detect
Write
Precompensation
MCU Interface
Time
Gradient
Estimator
Q
Pump
Samplers
Auto–Adapt
Estimator
DPLLFP
DPLLFM
VCO
Clk
7–Tap
Equalizer
Coefficients
Gain
Gradient
Thresholds
Offset
Cancel
Coefficients
IWRITE
WCSENSE
WCINHB
DAC
WCDAC
Data
BRSTA/DTP1
BRSTB/DTP2
BRSTC/DTP3
BRSTD/DTP4
SRVOUT
SRVREF
SRVRSTB
SRVSMPLB
Servo Demodulator
FWR
Peak Detector
Q
Pump
Servo
Pulse Detector
7–Pole
Filter
BST
FC
Q
Pump
SPOL
SERD
VGA
Mode
Zone Clk
Power
Manager
Frequency
Synthesizer
SYNTHFM
SYNTHFP
GND(7)
VCC(6)
Clamp
Mux
CLAMPB
VINP
VINM
HOLDB
CDATA
CSRVO
SRVOGT
RBIAS
CREG
CFILT
SLEEPB
FREF

# Microprocessor Bus Interface

Motorola offers a spectrum of line drivers and receivers which provide interfaces to many industry standard specifications. Many of the devices add key operational features, such as hysteresis, short circuit protection, clamp diode protection, or special control functions.

### Table 1. Magnetic Read/Write

| Device | Comments | $T_A$ (°C) | Suffix/ Package |
|---|---|---|---|
| MC3467* | Magnetic Tape Sense Amplifier. Trace independent preamplifiers with individual gain control. Optimized for use with 9–track magnetic tape memory systems. | 0 to + 70 | P/707 |

* Not recommended for new designs.

# Single–Ended Bus Transceivers

### Table 2. For Instrumentation Bus, Meets GPIB/IEEE Standard 488

| Driver Characteristics | | Receiver Characteristics | | | | |
|---|---|---|---|---|---|---|
| Output Current (mA) | Propagation Delay Max (ns) | Propagation Delay Max (ns) | Transceivers Per Package | Device | Suffix/ Package | Comments |
| 48 | 17 | 25 | 4 | MC3448A* | P/648, D/751B | Input hysteresis, open collector, 3–state outputs with terminations |

*Not recommended for new designs.

### Table 3. For High Current Party–Line Bus for Industrial and Data Communications

| Driver Characteristics | | Receiver Characteristics | | | | |
|---|---|---|---|---|---|---|
| Output Current (mA) | Propagation Delay Max (ns) | Propagation Delay Max (ns) | Transceivers Per Package | Device | Suffix/ Package | Comments |
| 100 | 15 | 15 | 4 | MC26S10* | P/648, D/751B | Open collector outputs, common enable |

*Not recommended for new designs.

# Line Receivers

### Table 4. General Purpose

| S = Single Ended D = Differential | Type of Output | $t_{prop}$ Delay Time Max (ns) | Party Line Operation | Strobe or Enable | Power Supplies (V) | Device | Suffix/ Package | Receivers Per Package | Companion Drivers | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| D | TP OC(1) | 25 | ✓ | ✓ | ±5.0 | MC3450* | P/648 | 4 | MC3453 | Quad |

(1) OC = Open Collector, TP = Totem–pole output.
* Note recommended for new designs.

### Table 5. EIA Standard

| S = Single Ended D = Differential | Type of Output | $t_{prop}$ Delay Time Max (ns) | Party Line Operation | Strobe or Enable | Power Supplies (V) | Device | Suffix/ Package | Receivers Per Package | Companion Drivers | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| S | TP | 4000 | – | – | +5.0 | MC14C89B, AB | P/646, D/751A | 4 | MC1488 MC14C88B | EIA–232–D/ EIA–562 |
| | R(1) | 85 | – | – | | MC1489 MC1489A | | | | EIA–232–D |
| S, D | TP | 30 | ✓ | ✓ | | AM26LS32* | PC/648 | | AM26LS31* | EIA–422/423 |
| | | 35 | | | | SN75175 | N/648, D/751B | | MC75174B | EIA–422/423/ 485 |

(1) R = Resistor Pull–up, TP = Totem–pole output.
* Not recommended for new designs.

# Line Drivers

## Table 6. EIA Standard

| Output Current Capability (mA) | $t_{prop}$ Delay Time Max (ns) | S = Single Ended D = Differential | Party Line Operation | Strobe or Enable | Power Supplies (V) | Device | Suffix/ Package | Drivers Per Package | Companion Receivers | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 85 | 35 | D | ✓ | ✓ | +5.0 | MC75174B MC75172B | P/648 | 4 | SN75175 | EIA–485 |
| 48 | 20 | | | | | AM26LS31* | PC/648 | | MC3486 AM26LS32* | EIA–422 with 3–state outputs |
| | | | | | | MC26LS31 | D/751B | | | |
| 15 | 3500 | S | – | | ±7.0 to ±12 | MC14C88B | P/646, D/751A | | MC14C89B MC14C89AB | EIA–232–D/ EIA–562 |
| 10 | 350 | | | | ±9.0 to ±12 | MC1488 | | | MC1489 MC1489A | EIA–232–D |
| 60 | 300 | S/D | | EIA–422 ✓ EIA–423 – | ±5.0 | AM26LS30 | PC/648 | 2 (422) 4 (423) | AM26LS32* | EIA–422 or EIA–423 Switchable |
| | | | | | | MC26LS30 | D/751B | | | |

* Not recommended for new designs.

7

## Table 7. Line Transceivers

| Driver Prop Delay (Max ns) | Receiver Prop Delay Max (ns) | DE =Driver Enable RE =Receiver Enable | Party Line Operation | Power Supplies (V) | Device | Suffix/ Package | Drivers Per Package | Receivers Per Package | EIA Standard |
|---|---|---|---|---|---|---|---|---|---|
| 23 | 23 | DE, RE | ✓ | +5.0 | MC34058 | FTA/932 | 6 | 6 | EIA–485 to 14 MBPS |
| | | | | | MC34059 | FTA/932 | 6 | 6 | EIA–485 to 20 MBPS |

## Table 8. EIA–232–E/V.28 CMOS Drivers/Receivers

| Device | Suffix/ Package | Pins | Drivers | Receivers | Power Supplies (V) | Features |
|---|---|---|---|---|---|---|
| MC145403 | P/738, DW/751D | 20 | 3 | 5 | ±5.0 to ±12 | |
| MC145404 | | | 4 | 4 | | |
| MC145405 | | | 5 | 3 | | |
| MC145406 | P/648, DW/751G, SD/940B | 16 | 3 | | | |
| MC145407 | P/738, DW/751D | 20 | | | +5.0 | Charge Pump |
| MC145408 | P/724, DW/751E, SD/940B | 24 | 5 | 5 | ±5.0 to ±12 | |
| MC145583 | DW/751F, VF/940J | 28 | 3 | 5 | +3.3 to +5.0 | On–board ring monitor circuit; charge pump, power down |
| MC145705 | P/738, DW/751D | 20 | 2 | 3 | +5.0 | Charge Pump, Power Down |
| MC145706 | | | 3 | 2 | | |
| MC145707 | P/724, DW/751E | 24 | | 3 | | |

### Table 9. Peripheral Drivers

| Output Current Capability (mA) | Input Capability | Propagation Delay Time Max (µs) | Output Clamp Diode | Off State Voltage Max (V) | Device | Drivers Per Package | Suffix/ Package | Logic Function |
|---|---|---|---|---|---|---|---|---|
| 500 | TTL, CMOS | 1.0 | ✓ | 50 | ULN2803 | 8 | A/707 | Invert |
| | 6.0 V to 15 V MOS | | | | ULN2804 | | | |
| | TTL, 5.0 V CMOS | | | | MC1413, B (ULN2003A) | 7 | P/648, D/751B | |
| | 8.0 V to 18 V MOS | | | | MC1416, B (ULN2004A) | | P/648, D/751B | |
| 1500 | TTL, 5.0 V CMOS | 1.0 | ✓ | 50 | ULN2068* | 4 | B/648C | Invert |

* Not recommended for new designs.

### Table 10. IEEE 802.3 Transceivers

| Device | Power Supply | 10 BaseT | NRZ | IEEE | Comments | Suffix/ Package |
|---|---|---|---|---|---|---|
| MC34055 | +5.0 Vdc | Transmit and Receive over 4 Pins | Raised ECL, CMOS | 802.3 Type 10BaseT | Transceiver with non–return to zero (NRZ) interface. Intended for but not restricted to concentrators and repeator applications. | DW/751E |
| MC68160 | | | TTL, CMOS | 802.3 Type 10BaseT/ AUI/NRZ | Interfaces gluelessly to Motorola's MC68360 communications controller. | FB/848D |

7

# Read/Write Channel

### Table 11. Hard Disk Drive Read Channel

| Device | Power Supply | Comments | $T_A$ (°C) | Suffix/ Package |
|---|---|---|---|---|
| MC34250 | 5.0 V | 200 Mbps fully integrated partial response maximum likelihood hard disk drive read/write channel which equalizes to a PR–IV shape and uses 8/9 rate (0, 4/4) coding. | 0 to +70 | FTA/840F |

# Inkjet Drivers

### Table 12. 28–Channel Inkjet Driver

| Device | Power Supply | Comments | $T_A$ (°C) | Suffix/ Package |
|---|---|---|---|---|
| MC34156 | 5.0 V | A 4 to 14 line decoder determines the selected output driver in each of two 14 driver banks. Two independent output enable lines permit 1 or 2 of 28 outputs. Outputs are open collector 30 V Darlington drivers capable of sinking 500 mA. | 0 to +70 | FN/777 |

# CMOS Display Drivers

These CMOS devices include digit as well as matrix drivers for LEDs, LCDs, and VFDs. They find applications over a wide range of end equipment such as instruments, automotive dashboards, home computers, appliances, radios and clocks.

## Table 13. Display Drivers

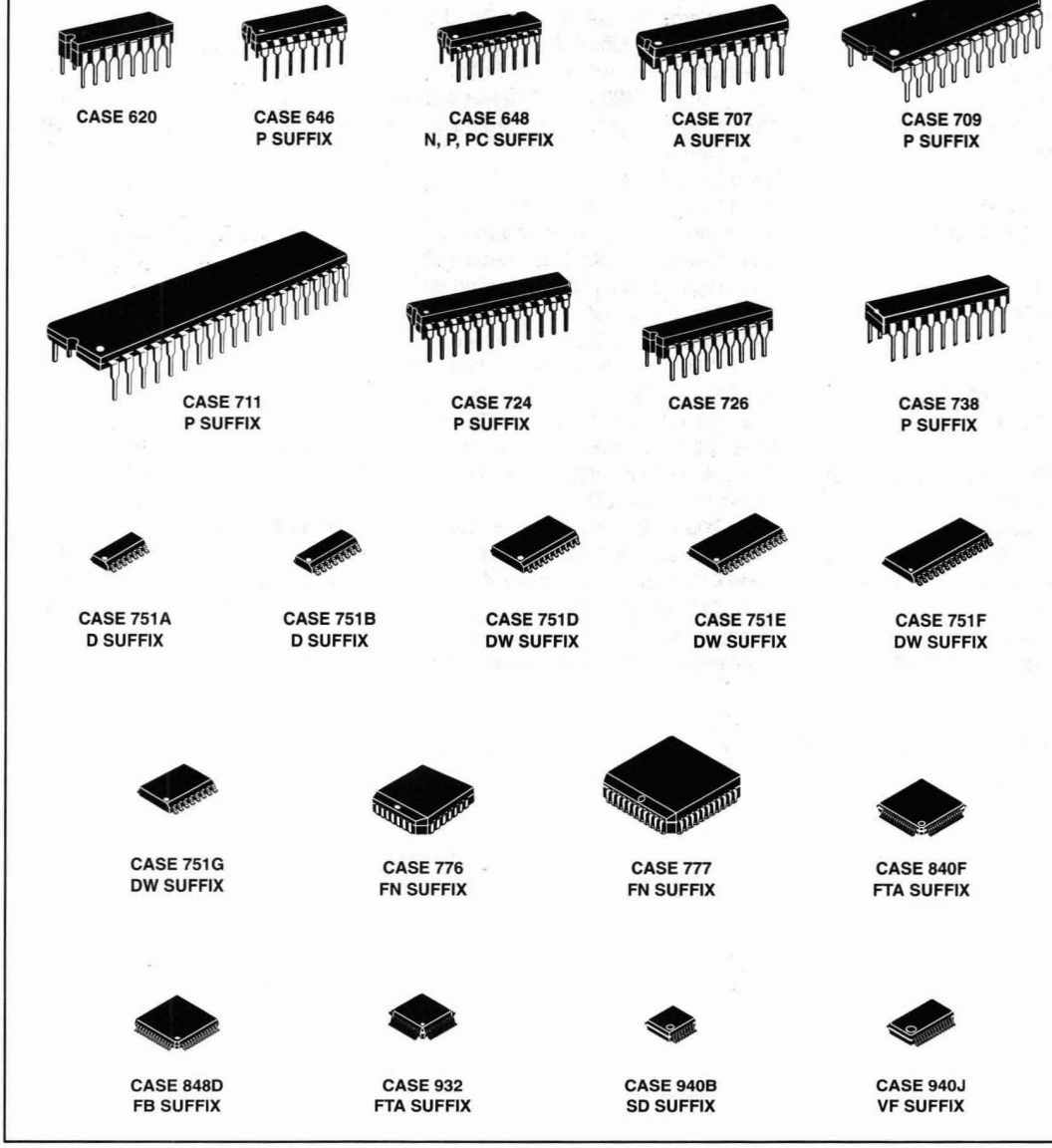
| Display Type | Input Format | Drive Capability Per Package | On–Chip Latch | Display Control | Segment Drive Current | Device |
|---|---|---|---|---|---|---|
| LCD (Direct Drive) | Parallel BCD | 7 Segments | ✓ | Blank | ≈ 1.0 mA | MC14543B |
| | | | | Blank, Ripple Blank | | MC14544B |
| | Serial Binary [Compatible with the Serial Peripheral Interface (SPI) on CMOS MCUs] | 33 Segments or Dots | | | 20 μA | MC145453 |
| Muxed LCD (1/4 Mux) | | 48 Segments or Dots | | | ≈ 200 μA | MC145000 |
| | | 44 Segments or Dots | | | | MC145001 |
| LED, Incandescent, Fluorescent(1) | Parallel BCD | 7 Segments | | Blank, Lamp Test | 25 mA | MC14511B |
| | | | | Blank, Ripple Blank, Lamp Test | | MC14513B |
| | | | – | Blank | 65 mA | MC14547B |
| Muxed LED (1/4 Mux) | Serial Binary [Compatible with the Serial Peripheral Interface (SPI) on CMOS MCUs] | 4 Digits + Decimals | ✓ | Oscillator (Scanner) | 50 mA (Peak) | MC14499 |
| Muxed LED (1/5 Mux) | | 5 Characters + Decimals or 25 Lamps | | Oscillator (Scanner), Low Power Mode, Dimming | 0 to 35 mA (Peak) Adjustable | MC14489 |
| LED (Direct Drive) | Parallel Hex | 7 Segments + A thru F Indicator | | | 10 mA(2) | MC14495–1 |
| (Interfaces to Display Drivers) | Parallel BCD | 7 Segments | – | Ripple Blank, Enable | – | MC14558B |

(1) Absolute maximum working voltage = 18 V.
(2) On–chip current–limiting resistor.

## Table 14. Functions

| Device | Function | Package |
|---|---|---|
| MC14489 | Multi–Character LED Display/Lamp Driver | 738, 751D |
| MC14495–1 | Hexadecimal–to–7 Segment Latch/Decoder ROM/Driver | 648, 751G |
| MC14499 | 4–Digit 7–Segment LED Display Decoder/Driver with Serial Interface | 707, 751D |
| MC14511B | BCD–to–7–Segment Latch/Decoder/Driver | 648, 751G |
| MC14513B | BCD–to–7–Segment Latch/Decoder/Driver with Ripple Blanking | 726, 707 |
| MC14543B | BCD–to–7–Segment Latch/Decoder/Driver for Liquid Crystals | 620, 648 |
| MC14544B | BCD–to–7–Segment Latch/Decoder/Driver with Ripple Blanking | 726, 707 |
| MC14547B | High–Current BCD–to–7–Segment Decoder/Driver | 620, 648 |
| MC14558B | BCD–to–7–Segment Decoder | 620, 648 |
| MC145000 | 48–Segment Serial Input Multiplexed LCD Driver (Master) | 709, 776 |
| MC145001 | 44–Segment Serial Input Multiplexed LCD Driver (Slave) | 707, 776 |
| MC145453 | 33–Segment, Non–Multiplexed LCD Driver with Serial Interface | 711, 777 |

# Interface Circuits Package Overview




7

# Device Listing

## Interface Circuits


| Device | Function | Page |
|---|---|---|
| **AM26LS30** | Dual Differential (EIA–422–A)/Quad Single–Ended (EIA–423–A) Line Drivers | 7–13 |
| **AM26LS31*** | Quad Line Driver with NAND Enabled Three–State Outputs | 7–24 |
| **AM26LS32*** | Quad EIA–422/423 Line Receiver with Three–State Outputs | 7–27 |
| **MC1413, B, MC1416, B** | High Voltage, High Current Darlington Transistor Arrays | 7–30 |
| **MC1488** | Quad Line Driver | 7–33 |
| **MC1489, A** | Quad Line Receivers | 7–39 |
| **MC14C88B** | Quad Low Power Line Driver | 7–44 |
| **MC14C89B, MC14C89AB** | Quad Low Power Line Receivers | 7–50 |
| **MC26S10*** | Ouad Open–Collector Bus Transceiver | 7–55 |
| **MC3448A*** | Quad Bidirectional Instrumentation Bus (GPIB) Transceiver | 7–58 |
| **MC3450*** | Quad MTTL Compatible Line Receivers | 7–64 |
| **MC3453*** | MTTL Compatible Quad Line Driver | 7–71 |
| **MC3467*** | Triple Wideband Preamplifier with Electronic Gain Control (EGC) | 7–76 |
| **MC3481*, MC3485*** | Quad Single–Ended Line Drivers | 7–81 |
| **MC3488A** | Dual EIA–423/EIA–232D Line Driver | 7–86 |
| **MC34055** | IEEE 802.3 10BASE–T Transceiver | 7–90 |
| **MC34058, MC34059** | Hex EIA–485 Transceiver with Three–State Outputs | 7–105 |
| **MC34156** | 28–Channel Inkjet Driver | 7–116 |
| **MC34250** | 5.0 V, 200 M–Bit/Sec PR–IV Hard Disk Drive Read Channel | 7–118 |
| **MC68160** | Enhanced Ethernet Transceiver | 7–120 |
| **MC75172B, MC75174B** | Quad EIA–485 Line Drivers with Three–State Outputs | 7–146 |
| **SN75175** | Quad EIA–485 Line Receiver | 7–157 |
| **ULN2068*** | Quad 1.5 A Sinking High Current Switch | 7–162 |
| **ULN2803, ULN2804** | Octal High Voltage, High Current Darlington Transistor Arrays | 7–166 |


**NOTE:** * Not recommended for new designs.

MOTOROLA

# AM26LS30

# Dual Differential (EIA-422-A)/ Quad Single-Ended (EIA-423-A) Line Drivers

**DUAL DIFFERENTIAL/ QUAD SINGLE–ENDED LINE DRIVERS**

**SEMICONDUCTOR TECHNICAL DATA**

The AM26LS30 is a low power Schottky set of line drivers which can be configured as two differential drivers which comply with EIA–422–A standards, or as four single–ended drivers which comply with EIA–423–A standards. A mode select pin and appropriate choice of power supplies determine the mode. Each driver can source and sink currents in excess of 50 mA.

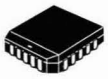
In the differential mode (EIA–422–A), the drivers can be used up to 10 Mbaud. A disable pin for each driver permits setting the outputs into a high impedance mode within a ±10 V common mode range.

In the single–ended mode (EIA–423–A), each driver has a slew rate control pin which permits setting the slew rate of the output signal so as to comply with EIA–423–A and FCC requirements and to reduce crosstalk. When operated from symmetrical supplies (±5.0 V), the outputs exhibit zero imbalance.

The AM26LS30 is available in a 16–pin plastic DIP and surface mount package. Operating temperature range is –40° to +85°C.

- Operates as Two Differential EIA–422–A Drivers, or Four Single–Ended EIA–423–A Drivers
- High Impedance Outputs in Differential Mode
- Short Circuit Current Limit In Both Source and Sink Modes
- ± 10 V Common Mode Range on High Impedance Outputs
- ± 15 V Range on Inputs
- Low Current PNP Inputs Compatible with TTL, CMOS, and MOS Outputs
- Individual Output Slew Rate Control in Single–Ended Mode
- Replacement for the AMD AM25LS30 and National Semiconductor DS3691

**PC SUFFIX**
PLASTIC PACKAGE
CASE 648

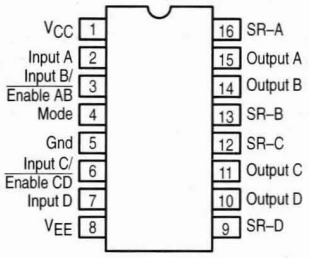


**FN SUFFIX**
PLASTIC PACKAGE
CASE 775

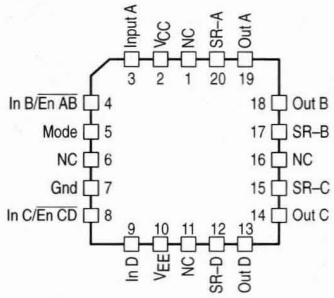
**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

7

**PIN CONNECTIONS**

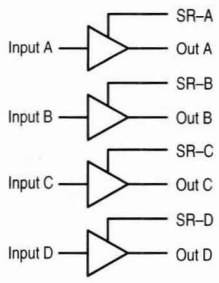



(Top View)

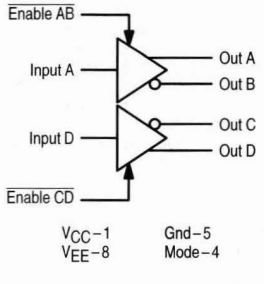



**Representative Block Diagrams**

**Single–Ended Mode EIA–423–A**




**Differential Mode EIA–422–A**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| AM26LS30PC | $T_A$ = – 40° to +85°C | Plastic DIP |
| MC26LS30D | | SO–16 |
| AM26LS30FN | | PLCC–20 |

**MAXIMUM OPERATING CONDITIONS** (Pin numbers refer to DIP and SO–16 packages only.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$<br>$V_{EE}$ | –0.5, +7.0<br>–7.0, +0.5 | Vdc |
| Input Voltage (All Inputs) | $V_{in}$ | –0.5, +20 | Vdc |
| Applied Output Voltage when in High Impedance Mode ($V_{CC}$ = 5.0 V, Pin 4 = Logic 0, Pins 3, 6 = Logic 1) | $V_{za}$ | ±15 | Vdc |
| Output Voltage with $V_{CC}$, $V_{EE}$ = 0 V | $V_{zb}$ | ±15 | |
| Output Current | $I_O$ | Self limiting | – |
| Junction Temperature | $T_J$ | –65, +150 | °C |

Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides conditions for actual device operation.

**RECOMMENDED OPERATING CONDITIONS**

| Rating | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage (Differential Mode) | $V_{CC}$<br>$V_{EE}$ | +4.75<br>–0.5 | 5.0<br>0 | +5.25<br>+0.3 | Vdc |
| Power Supply Voltage (Single–Ended Mode) | $V_{CC}$<br>$V_{EE}$ | +4.75<br>–5.25 | +5.0<br>–5.0 | +5.25<br>–4.75 | |
| Input Voltage (All Inputs)<br>Applied Output Voltage (when in High Impedance Mode)<br>Applied Output Voltage, $V_{CC}$ = 0 | $V_{in}$<br>$V_{za}$<br>$V_{zb}$ | 0<br>–10<br>–10 | –<br>–<br>– | +15<br>+10<br>+10 | Vdc |
| Output Current | $I_O$ | –65 | – | +65 | mA |
| Operating Ambient Temperature (See text) | $T_A$ | –40 | – | +85 | °C |

All limits are not necessarily functional concurrently.

**ELECTRICAL CHARACTERISTICS** (EIA–422–A differential mode, Pin 4 ≤ 0.8 V, –40°C < $T_A$ < 85°C, 4.75 V ≤ $V_{CC}$ ≤ 5.25 V, $V_{EE}$ = Gnd, unless otherwise noted. Pin numbers refer to DIP and SO–16 packages only.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Voltage (see Figure 1) | | | | | |
| Differential, $R_L$ = ∞, $V_{CC}$ = 5.25 V | $\lvert V_{OD1} \rvert$ | – | 4.2 | 6.0 | Vdc |
| Differential, $R_L$ = 100 Ω, $V_{CC}$ = 4.75 V | $\lvert V_{OD2} \rvert$ | 2.0 | 2.6 | – | Vdc |
| Change in Differential Voltage, $R_L$ = 100 Ω (Note 4) | $\lvert \Delta V_{OD2} \rvert$ | – | 10 | 400 | mVdc |
| Offset Voltage, $R_L$ = 100 Ω | $V_{OS}$ | – | 2.5 | 3.0 | Vdc |
| Change in Offset Voltage*, $R_L$ = 100 Ω | $\lvert \Delta V_{OS} \rvert$ | – | 10 | 400 | mVdc |
| Output Current (each output) | | | | | |
| Power Off Leakage, $V_{CC}$ = 0, –10 V ≤ $V_O$ ≤ +10 V | $I_{OLK}$ | –100 | 0 | +100 | µA |
| High Impedance Mode, $V_{CC}$ = 5.25 V, –10 V ≤ $V_O$ ≤ +10 V | $I_{OZ}$ | –100 | 0 | +100 | |
| Short Circuit Current (Note 2) | | | | | |
| High Output Shorted to Pin 5 ($T_A$ = 25°C) | $I_{SC-}$ | –150 | –95 | –60 | mA |
| High Output Shorted to Pin 5 (–40°C < $T_A$ <+85°C) | $I_{SC-}$ | –150 | – | –50 | |
| Low Output Shorted to +6.0 V ($T_A$ = 25°C) | $I_{SC+}$ | 60 | 75 | 150 | |
| Low Output Shorted to +6.0 V (–40°C < $T_A$ < +85°C) | $I_{SC+}$ | 50 | – | 150 | |
| Inputs | | | | | |
| Low Level Voltage | $V_{IL}$ | – | – | 0.8 | Vdc |
| High Level Voltage | $V_{IH}$ | 2.0 | – | – | Vdc |
| Current @ $V_{in}$ = 2.4 V | $I_{IH}$ | – | 0 | 40 | µA |
| Current @ $V_{in}$ = 15 V | $I_{IHH}$ | – | 0 | 100 | |
| Current @ $V_{in}$ = 0.4 V | $I_{IL}$ | –200 | –8.0 | – | |
| Current, 0 ≤ $V_{in}$ ≤ 15 V, $V_{CC}$ = 0 | $I_{IX}$ | – | 0 | – | |
| Clamp Voltage ($I_{in}$ = –12 mA) | $V_{IK}$ | –1.5 | – | – | Vdc |
| Power Supply Current ($V_{CC}$ = +5.25 V, Outputs Open)<br>(0 ≤ Enable ≤ $V_{CC}$) | $I_{CC}$ | – | 16 | 30 | mA |

**NOTES:** 1. All voltages measured with respect to Pin 5.
2. Only one output shorted at a time, for not more than 1 second.
3. Typical values established at +25°C, $V_{CC}$ = +5.0 V, $V_{EE}$ = –5.0 V.
4. $V_{in}$ switched from 0.8 to 2.0 V.
5. Imbalance is the difference between $\lvert V_{O2} \rvert$ with $V_{in}$ < 0.8 V and $\lvert V_{O2} \rvert$ with $V_{in}$ > 2.0 V.

**TIMING CHARACTERISTICS** (EIA–422–A differential mode, Pin 4 ≤ 0.8 V, $T_A$ = 25°C, $V_{CC}$ = 5.0 V, $V_{EE}$ = Gnd, (Notes 1 and 3) unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Differential Output Rise Time (Figure 3) | $t_r$ | – | 70 | 200 | ns |
| Differential Output Fall Time (Figure 3) | $t_f$ | – | 70 | 200 | ns |
| Propagation Delay Time – Input to Differential Output | | | | | ns |
| Input Low to High (Figure 3) | $t_{PDH}$ | – | 90 | 200 | |
| Input High to Low (Figure 3) | $t_{PDL}$ | – | 90 | 200 | |
| Skew Timing (Figure 3) | | | | | ns |
| $\lvert t_{PDH}$ to $t_{PDL}\rvert$ for Each Driver | $t_{SK1}$ | – | 9.0 | – | |
| Max to Min $t_{PDH}$ Within a Package | $t_{SK2}$ | – | 2.0 | – | |
| Max to Min $t_{PDL}$ Within a Package | $t_{SK3}$ | – | 2.0 | – | |
| Enable Timing (Figure 4) | | | | | ns |
| Enable to Active High Differential Output | $t_{PZH}$ | – | 150 | 300 | |
| Enable to Active Low Differential Output | $t_{PZL}$ | – | 190 | 350 | |
| Enable to 3–State Output From Active High | $t_{PHZ}$ | – | 80 | 350 | |
| Enable to 3–State Output From Active Low | $t_{PLZ}$ | – | 110 | 300 | |

**ELECTRICAL CHARACTERISTICS** (EIA–423–A single–ended mode, Pin 4 ≥ 2.0 V, –40°C < $T_A$ < 85°C, 4.75 V ≤ $\lvert V_{CC}\rvert$, $\lvert V_{EE}\rvert$ ≤ 5.25 V, (Notes 1 and 3) unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Voltage ($V_{CC}$ = $\lvert V_{EE}\rvert$ = 4.75 V) | | | | | Vdc |
| Single–Ended Voltage, $R_L$ = ∞ (Figure 2) | $\lvert V_{O1}\rvert$ | 4.0 | 4.2 | 6.0 | |
| Single–Ended Voltage, $R_L$ = 450 Ω, (Figure 2) | $\lvert V_{O2}\rvert$ | 3.6 | 3.95 | 6.0 | |
| Voltage Imbalance (Note 5), $R_L$ = 450 Ω | $\lvert \Delta V_{O2}\rvert$ | – | 0.05 | 0.4 | |
| Slew Control Current (Pins 16, 13, 12, 9) | $I_{SLEW}$ | – | ±120 | – | µA |
| Output Current (Each Output) | | | | | |
| Power Off Leakage, $V_{CC}$ = $V_{EE}$ = 0, –6.0 V ≤ $V_O$ ≤ +6.0 V | $I_{OLK}$ | –100 | 0 | +100 | µA |
| Short Circuit Current (Output Short to Ground, Note 2) | | | | | |
| $V_{in}$ ≤ 0.8 V ($T_A$ = 25°C) | $I_{SC+}$ | 60 | 80 | 150 | mA |
| $V_{in}$ ≤ 0.8 V (–40°C < $T_A$ < +85°C) | $I_{SC+}$ | 50 | – | 150 | |
| $V_{in}$ ≥ 2.0 V ($T_A$ = 25°C) | $I_{SC–}$ | –150 | –95 | –60 | |
| $V_{in}$ ≥ 2.0 V (–40°C < $T_A$ < +85°C) | $I_{SC–}$ | –150 | – | –50 | |
| Inputs | | | | | |
| Low Level Voltage | $V_{IL}$ | – | – | 0.8 | Vdc |
| High Level Voltage | $V_{IH}$ | 2.0 | – | – | Vdc |
| Current @ $V_{in}$ = 2.4 V | $I_{IH}$ | – | 0 | 40 | µA |
| Current @ $V_{in}$ = 15 V | $I_{IHH}$ | – | 0 | 100 | |
| Current @ $V_{in}$ = 0.4 V | $I_{IL}$ | –200 | –8.0 | – | |
| Current, 0 ≤ $V_{in}$ ≤ 15 V, $V_{CC}$ = 0 | $I_{IX}$ | – | 0 | – | |
| Clamp Voltage ($I_{in}$ = –12 mA) | $V_{IK}$ | –1.5 | – | – | Vdc |
| Power Supply Current (Outputs Open) | $I_{CC}$ | – | 17 | 30 | mA |
| $V_{CC}$ = +5.25 V, $V_{EE}$ = –5.25 V, $V_{in}$ = 0.4 V | $I_{EE}$ | –22 | –8.0 | – | |

**TIMING CHARACTERISTICS** (EIA–423–A single–ended mode, Pin 4 ≥ 2.0 V, $T_A$ = 25°C, $V_{CC}$ = 5.0 V, $V_{EE}$ = –5.0 V, (Notes 1 and 3) unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Timing (Figure 5) | | | | | |
| Output Rise Time, $C_C$ = 0 | $t_r$ | – | 65 | 300 | ns |
| Output Fall Time, $C_C$ = 0 | $t_f$ | – | 65 | 300 | |
| Output Rise Time, $C_C$ = 50 pF | $t_r$ | – | 3.0 | – | µs |
| Output Fall Time, $C_C$ = 50 pF | $t_f$ | – | 3.0 | – | |
| Rise Time Coefficient (Figure 16) | $C_{rt}$ | – | 0.06 | – | µs/pF |
| Propagation Delay Time, Input to Single Ended Output (Figure 5) | | | | | ns |
| Input Low to High, $C_C$ = 0 | $t_{PDH}$ | – | 100 | 300 | |
| Input High to Low, $C_C$ = 0 | $t_{PDL}$ | – | 100 | 300 | |
| Skew Timing, $C_C$ = 0 (Figure 5) | | | | | ns |
| $\lvert t_{PDH}$ to $t_{PDL}\rvert$ for Each Driver | $t_{SK4}$ | – | 15 | – | |
| Max to Min $t_{PDH}$ Within a Package | $t_{SK5}$ | – | 2.0 | – | |
| Max to Min $t_{PDL}$ Within a Package | $t_{SK6}$ | – | 5.0 | – | |

**Table 1**

| Operation | $V_{CC}$ | $V_{EE}$ | Inputs | | | | | Outputs | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mode | A | B | C | D | A | B | C | D |
| Differential (EIA–422–A) | +5.0 | Gnd | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | | | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| | | | 0 | X | 1 | 0 | 1 | Z | Z | 0 | 1 |
| | | | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| | | | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | | | 0 | 1 | 0 | 1 | X | 1 | 0 | Z | Z |
| Single–Ended (EIA–423–A) | +5.0 | –5.0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| X | 0 | X | X | X | X | X | X | Z | Z | Z | Z |

X = Don't Care
Z = High Impedance (Off)

**Figure 1. Differential Output Test**

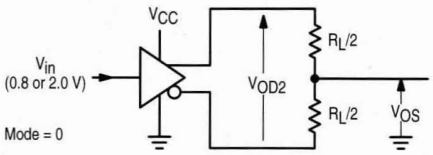



**Figure 2. Single–Ended Output Test**

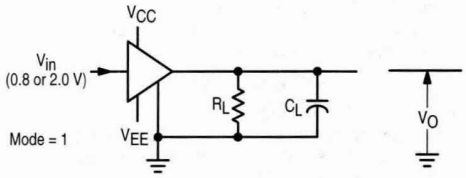
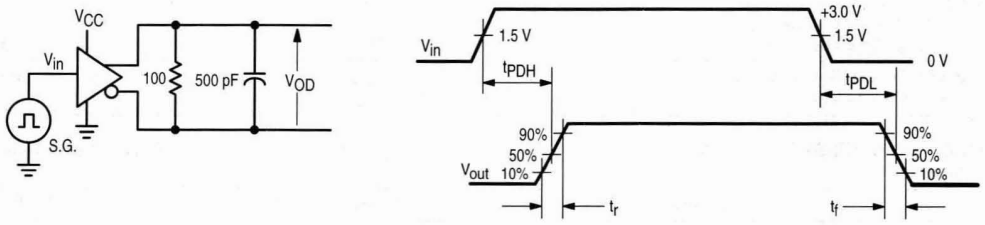
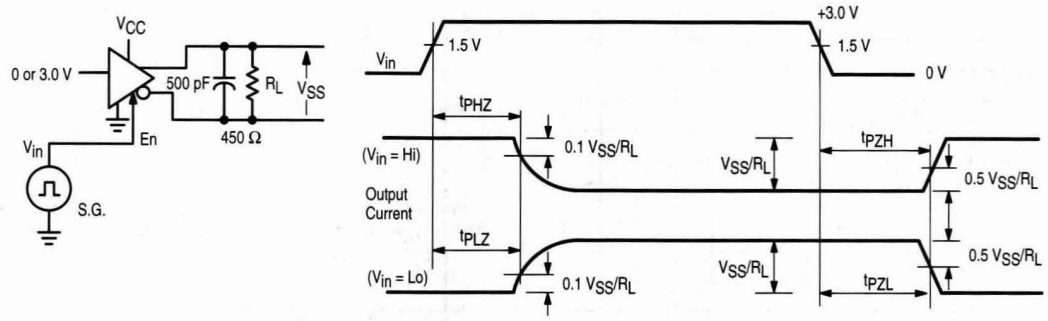



**Figure 3. Differential Mode Rise/Fall Time and Data Propagation Delay**




**NOTES:** 1. S.G. set to: f ≤ 1.0 MHz; duty cycle = 50%; $t_r$, $t_f$, ≤ 10 ns.
2. $t_{SK1} = |t_{PDH} - t_{PDL}|$ for each driver.
3. $t_{SK2}$ computed by subtracting the shortest $t_{PDH}$ from the longest $t_{PDH}$ of the 2 drivers within a package.
4. $t_{SK3}$ computed by subtracting the shortest $t_{PDL}$ from the longest $t_{PDL}$ of the 2 drivers within a package.

**Figure 4. Differential Mode Enable Timing**




**NOTES:** 1. S.G. set to: f ≤ 1.0 MHz; duty cycle = 50%; $t_r$, $t_f$, ≤ 10 ns.
2. Above tests conducted by monitoring output current levels.

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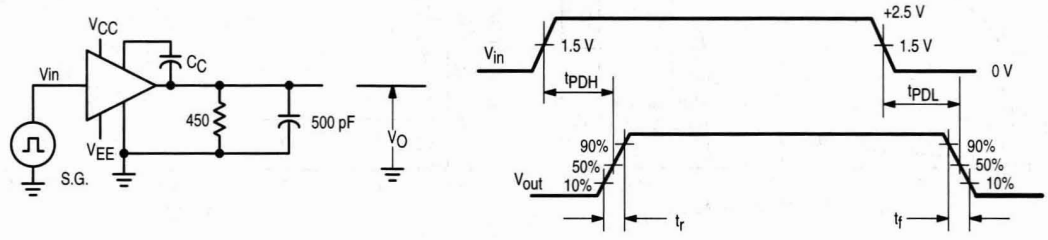
**Figure 5. Single–Ended Mode Rise/Fall Time and Data Propagation Delay**




**NOTES:** 1. S.G. set to: f ≤ 100 kHz; duty cycle = 50%; $t_r$, $t_f$, ≤ 10 ns.
2. $t_{SK4} = |t_{PDH} - t_{PDL}|$ for each driver.
3. $t_{SK5}$ computed by subtracting the shortest $t_{PDH}$ from the longest $t_{PDH}$ of the 4 drivers within a package.
4. $t_{SK6}$ computed by subtracting the shortest $t_{PDL}$ from the longest $t_{PDL}$ of the 4 drivers within a package.

**Figure 6. Differential Output Voltage versus Load Current**

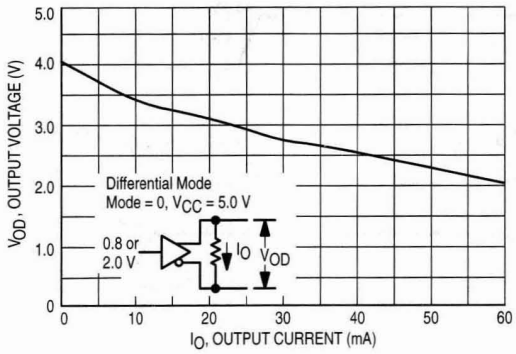



**Figure 7. Internal Bias Current versus Load Current**

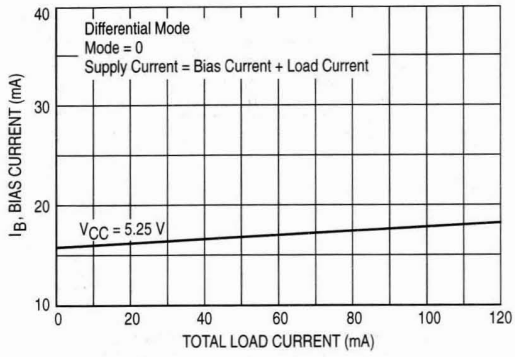



**Figure 8. Short Circuit Current versus Output Voltage**

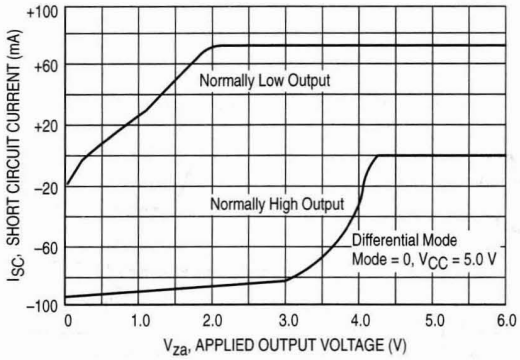



**Figure 9. Input Current versus Input Voltage**

(Pin numbers refer to DIP and SO–16 packages only.)

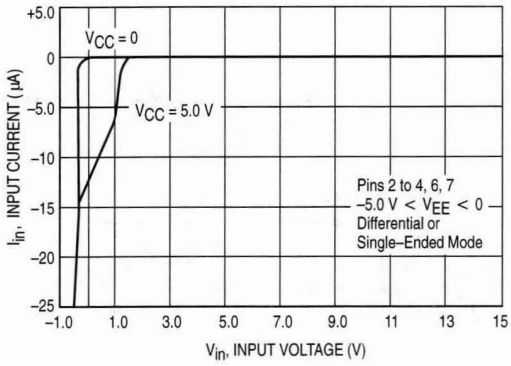



**Figure 10. Output Voltage versus Output Source Current**

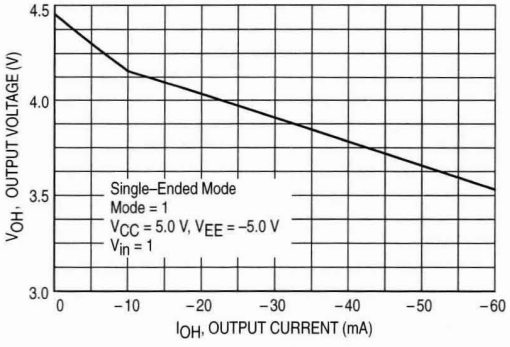



**Figure 11. Output Voltage versus Output Sink Current**

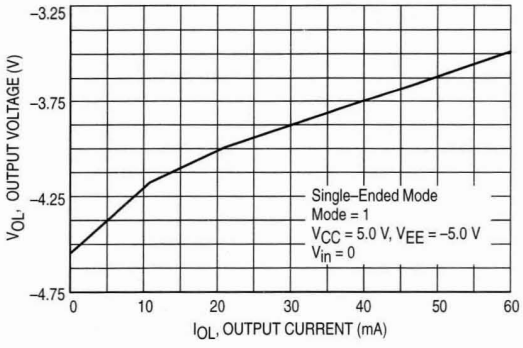



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**Figure 12. Internal Positive Bias Current versus Load Current**

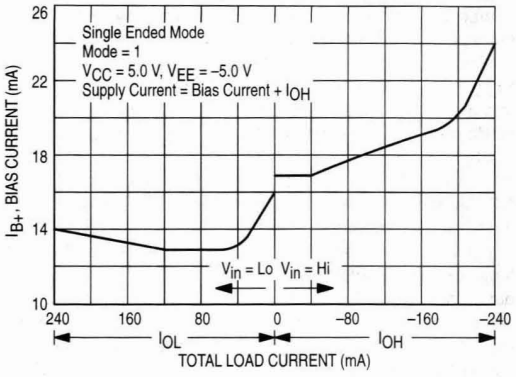

Single Ended Mode
Mode = 1
VCC = 5.0 V, VEE = –5.0 V
Supply Current = Bias Current + IOH
Vin = Lo Vin = Hi
IB+, BIAS CURRENT (mA)
TOTAL LOAD CURRENT (mA)
IOL
IOH

**Figure 13. Internal Negative Bias Current versus Load Current**

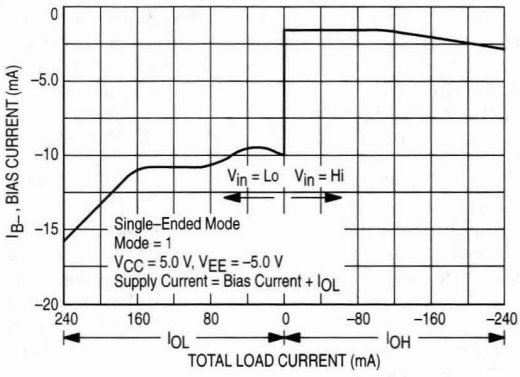

Vin = Lo Vin = Hi
Single–Ended Mode
Mode = 1
VCC = 5.0 V, VEE = –5.0 V
Supply Current = Bias Current + IOL
IB–, BIAS CURRENT (mA)
TOTAL LOAD CURRENT (mA)
IOL
IOH

**Figure 14. Short Circuit Current versus Output Voltage**

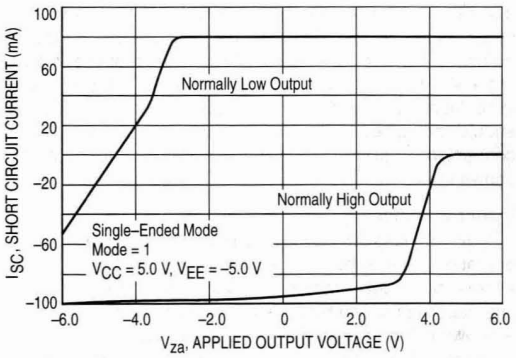

Normally Low Output
Normally High Output
Single–Ended Mode
Mode = 1
VCC = 5.0 V, VEE = –5.0 V
ISC, SHORT CIRCUIT CURRENT (mA)
Vza, APPLIED OUTPUT VOLTAGE (V)

**Figure 15. Short Circuit Current versus Temperature**

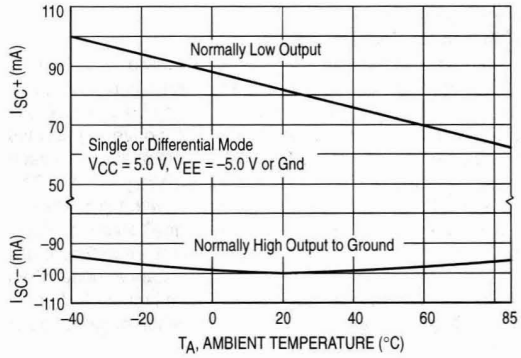
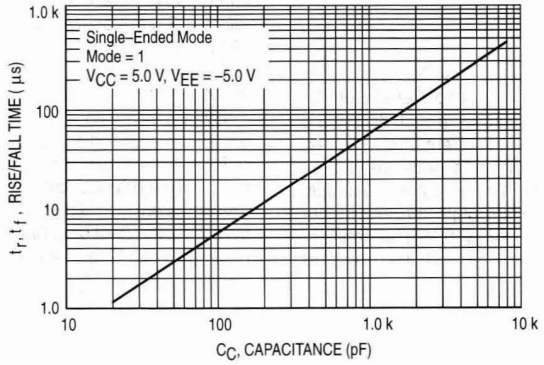

Normally Low Output
Single or Differential Mode
VCC = 5.0 V, VEE = –5.0 V or Gnd
Normally High Output to Ground
ISC+ (mA)
ISC– (mA)
TA, AMBIENT TEMPERATURE (°C)

**Figure 16. Rise/Fall Time versus Capacitance**



## APPLICATIONS INFORMATION

(Pin numbers refer to DIP and SO–16 packages only.)

### Description

The AM26LS30 is a dual function line driver – it can be configured as two differential output drivers which comply with EIA–422–A Standard, or as four single–ended drivers which comply with EIA–423–A Standard. The mode of operation is selected with the Mode pin (Pin 4) and appropriate power supplies (see Table 1). Each of the four outputs is capable of sourcing and sinking 60 to 70 mA while providing sufficient voltage to ensure proper data transmission.

As differential drivers, data rates to 10 Mbaud can be transmitted over a twisted pair for a distance determined by the cable characteristics. EIA–422–A Standard provides guidelines for cable length versus data rate. The advantage of a differential (balanced) system over a single–ended system is greater noise immunity, common mode rejection, and higher data rates.

Where extraneous noise sources are not a problem, the AM26LS30 may be configured as four single–ended drivers transmitting data rates to 100 Kbaud. Crosstalk among wires within a cable is controlled by the use of the slew rate control pins on the AM26LS30.



### Mode Selection

**(Differential Mode)**

In this mode (Pins 4 and 8 at ground), only a +5.0 V supply ±5% is required at $V_{CC}$. Pins 2 and 7 are the driver inputs, while Pins 10, 11, 14 and 15 are the outputs (see Block Diagram on page 1). The two outputs of a driver are always complementary and the differential voltage available at each pair of outputs is shown in Figure 6 for $V_{CC}$ = 5.0 V. The differential output voltage will vary directly with $V_{CC}$. A "high" output can only source current, while a "low" output can only sink current (except for short circuit current – see Figure 8).

The two outputs will be in a high impedance mode when the respective Enable input (Pin 3 or 6) is high, or if $V_{CC} \leq$ 1.1 V. Output leakage current over a common mode range of ± 10 V is typically less than 1.0 µA.

The outputs have short circuit current limiting, typically, less than 100 mA over a voltage range of 0 to +6.0 V (see Figure 8). Short circuits should not be allowed to last indefinitely as the IC may be damaged.

Pins 9, 12, 13 and 16 are not normally used when in this mode, and should be left open.

**(Single–Ended Mode)**

In this mode (Pin 4 ≥ 2.0 V) $V_{CC}$ requires +5.0 V, and $V_{EE}$ requires –5.0 V, both ±5.0%. Pins 2, 3, 6, and 7 are inputs for the four drivers, and Pins 15, 14, 11, and 10 (respectively) are the outputs. The four drivers are independent of each other, and each output will be at a positive or a negative voltage depending on its input state, the load current, and the supply voltage. Figures 10 & 11 indicate the high and low output voltages for $V_{CC}$ = 5.0 V, and $V_{EE}$ = –5.0 V. The graph of Figure 10 will vary directly with $V_{CC}$, and the graph of Figure 11 will vary directly with $V_{EE}$. A "high" output can only source current, while a "low" output can only sink current (except short circuit current – see Figure 14).

The outputs will be in a high impedance mode only if $V_{CC} \leq$ 1.1 V. Changing $V_{EE}$ to 0 V does not set the outputs to a high impedance mode. Leakage current over a common mode range of ±10 V is typically less than 1.0 µA.

The outputs have short circuit current limiting, typically less than 100 mA over a voltage range of ±6.0 V (see Figure 14). Short circuits should not be allowed to last indefinitely as the IC may be damaged.

Capacitors connected between Pins 9, 12, 13, and 16 and their respective outputs will provide slew rate limiting of the output transition. Figure 16 indicates the required capacitor value to obtain a desired rise or fall time (measured between the 10% and 90% points). The positive and negative transition times will be within ≈ ±5% of each other. Each output may be set to a different slew rate if desired.

### Inputs

The five inputs determine the state of the outputs in accordance with Table 1. All inputs (regardless of the operating mode) have a nominal threshold of +1.3 V, and their voltage must be kept within a range of 0 V to +15 V for proper operation. If an input is taken more than 0.3 V below ground, excessive currents will flow, and the proper operation of the drivers will be affected. An open pin is equivalent to a logic high, but good design practices dictate that inputs should never be left open. Unused inputs should be connected to ground. The characteristics of the inputs are shown in Figure 9.

### Power Supplies

$V_{CC}$ requires +5.0 V, ±5%, regardless of the mode of operation. The supply current is determined by the IC's internal bias requirements and the total load current. The internally required current is a function of the load current and is shown in Figure 7 for the differential mode.

In the single–ended mode, $V_{EE}$ must be –5.0 V, ±5% in order to comply with EIA–423–A standards. Figures 12 and 13 indicate the internally required bias currents as a function of total load current (the sum of the four output loads). The discontinuity at 0 load current exists due to a change in bias current when the inputs are switched. The supply currents vary ≈ ± 2.0 mA as $V_{CC}$ and $V_{EE}$ are varied from |4.75 V| to |5.25 V|.

Sequencing of the supplies during power–up/power–down is not required.

Bypass capacitors (0.1 µF minimum on each supply pin) are recommended to ensure proper operation. Capacitors reduce noise induced onto the supply lines by the switching action of the drivers, particularly where long P.C. board tracks are involved. Additionally, the capacitors help absorb transients induced onto the drivers' outputs from the external cable (from ESD, motor noise, nearby computers, etc.).

**Operating Temperature Range**

The maximum ambient operating temperature, listed as +85°C, is actually a function of the system use (i.e., specifically how many drivers within a package are used) and at what current levels they are operating. The maximum power which may be dissipated within the package is determined by:

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{R_{\theta JA}}$$

where $R_{\theta JA}$ = package thermal resistance which is typically:
67°C/W for the DIP (PC) package,
120°C/W for the SOIC (D) package,
$T_{Jmax}$ = max. allowable junction temperature (150°C)
$T_A$ = ambient air temperature near the IC package.

1) Differential Mode Power Dissipation

For the differential mode, the power dissipated within the package is calculated from:

$P_D = [(V_{CC} - V_{OD}) \times I_O]$ (each driver) + $(V_{CC} \times I_B)$

where: $V_{CC}$ = the supply voltage
$V_{OD}$ = is taken from Figure 6 for the known value of $I_O$
$I_B$ = the internal bias current (Figure 7)

As indicated in the equation, the first term (in brackets) must be calculated and summed for each of the two drivers, while the last term is common to the entire package. Note that the term $(V_{CC} - V_{OD})$ is constant for a given value of $I_O$ and does not vary with $V_{CC}$. For an application involving the following conditions:

$T_A$ = +85°C, $I_O$ = –60 mA (each driver), $V_{CC}$ = 5.25 V, the suitability of the package types is calculated as follows.

The power dissipated is:

$P_D = [3.0\ V \times 60\ mA \times 2] + (5.25\ V \times 18\ mA)$
$P_D = 454$ mW

The junction temperature calculates to:

$T_J$ = 85°C + (0.454 W × 67°C/W) = 115°C for the DIP package,
$T_J$ = 85°C + (0.454 W × 120°C/W) = 139°C for the SOIC package.

Since the maximum allowable junction temperature is not exceeded in any of the above cases, either package can be used in this application.

2) Single–Ended Mode Power Dissipation

For the single–ended mode, the power dissipated within the package is calculated from:

$$P_D = (I_{B+} \times V_{CC}) + (I_{B-} \times V_{EE}) + [(I_O \times (V_{CC} - V_{OH})] \text{(each driver)}$$

The above equation assumes $I_O$ has the same magnitude for both output states, and makes use of the fact that the absolute value of the graphs of Figures 10 and 11 are nearly identical. $I_{B+}$ and $I_{B-}$ are obtained from the right half of Figures 12 and 13, and $(V_{CC} - V_{OH})$ can be obtained from Figure 10. Note that the term $(V_{CC} - V_{OH})$ is constant for a given value of $I_O$ and does not vary with $V_{CC}$. For an application involving the following conditions:

$T_A$ = +85°C, $I_O$ = –60 mA (each driver), $V_{CC}$ = 5.25 V, $V_{EE}$ = –5.25 V, the suitability of the package types is calculated as follows.

The power dissipated is:

$P_D = (24\ mA \times 5.25\ V) + (-3.0\ mA \times -5.25\ V) + [60\ mA \times 1.45\ V \times 4.0]$
$P_D = 490$ mW

The junction temperature calculates to:

$T_J$ = 85°C + (0.490 W × 67°C/W) = 118°C for the DIP package,
$T_J$ = 85°C + (0.490 W × 120°C/W) = 144°C for the SOIC package.

Since the maximum allowable junction temperature is not exceeded in any of the above cases, either package can be used in this application.

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## SYSTEM EXAMPLES

(Pin numbers refer to DIP and SO–16 packages only.)

### Differential System

An example of a typical EIA–422–A system is shown in Figure 17. Although EIA–422–A does not specifically address multiple driver situations, the AM26LS30 can be used in this manner since the outputs can be put into a high impedance mode. It is, however, the system designer's responsibility to ensure the Enable pins are properly controlled so as to prevent two drivers on the same cable from being "on" at the same time.

The limit on the number of receivers and drivers which may be connected on one system is determined by the input current of each receiver, the maximum leakage current of each "off" driver, and the DC current through each terminating resistor. The sum of these currents must not exceed the capability of the "on" driver (≈60 mA). If the cable is of any significant length, with receivers at various points along its length, the common mode voltage may vary along its length, and this parameter must be considered when calculating the maximum driver current.

The cable requirements are defined not only by the AC characteristics and the data rate, but also by the DC resistance. The maximum resistance must be such that the minimum voltage across any receiver inputs is never less than 200 mV.

7

The ground terminals of each driver and receiver in Figure 17 must be connected together by a dedicated wire (or the shield) in the cable to provide a common reference. Chassis grounds or power line grounds should not be relied on for this common connection as they may generate significant common mode differences. Additionally, they usually do not provide a sufficiently low impedance at the frequencies of interest.

### Single–Ended System

An example of a typical EIA–423–A system is shown in Figure 18. Multiple drivers on a single data line are not possible since the drivers cannot be put into a high impedance mode. Although each driver is shown connected to a single receiver, multiple receivers can be driven from a single driver as long as the total load current of the receivers and the terminating resistor does not exceed the capability of the driver (≈60 mA). If the cable is of any significant length, with receivers at various points along its length, the common mode voltage may vary along its length, and this parameter must be considered when calculating the maximum driver current.

The cable requirements are defined not only by the AC characteristics and the data rate, but also by the DC resistance. The maximum resistance must be such that the minimum voltage across any receiver inputs is never less than 200 mV.

The ground terminals of each driver and receiver in Figure 18 must be connected together by a dedicated wire (or the shield) in the cable so as to provide a common reference. Chassis grounds or power line grounds should not be relied on for this common connection as they may generate significant common mode differences. Additionally, they usually do not provide a sufficiently low impedance at the frequencies of interest.

### Additional Modes of Operation

If compliance with EIA–422–A or EIA–423–A Standard is not required in a particular application, the AM26LS30 can be operated in two other modes.

1) The device may be operated in the differential mode (Pin 4 = 0) with $V_{EE}$ connected to any voltage between ground and –5.25 V. Outputs in the low state will be referenced to $V_{EE}$, resulting in a differential output voltage greater than that shown in Figure 6. The Enable pins will operate the same as previously described.

2) The device may be operated in the single–ended mode (Pin 4 = 1) with $V_{EE}$ connected to any voltage between ground and –5.25 V. Outputs in the high state will be at a voltage as shown in Figure 10, while outputs in a low state will be referenced to $V_{EE}$.

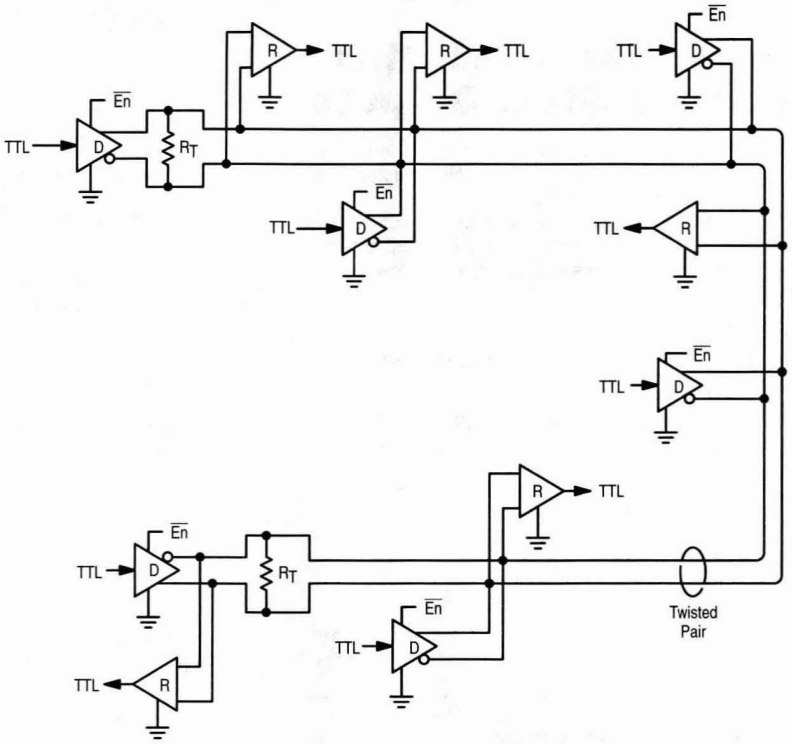
### Termination Resistors

Transmission line theory states that, in order to preserve the shape and integrity of a waveform traveling along a cable, the cable must be terminated in an impedance equal to its characteristic impedance. In a system such as that depicted in Figure 17, in which data can travel in both directions, both physical ends of the cable must be terminated. Stubs leading to each receiver and driver should be as short as possible.

In a system such as that depicted in Figure 18, in which data normally travels in one direction only, a terminator is theoretically required only at the receiving end of the cable. However, if the cable is in a location where noise spikes of several volts can be induced onto it, then a terminator (preferably a series resistor) should be placed at the driver end to prevent damage to the driver.

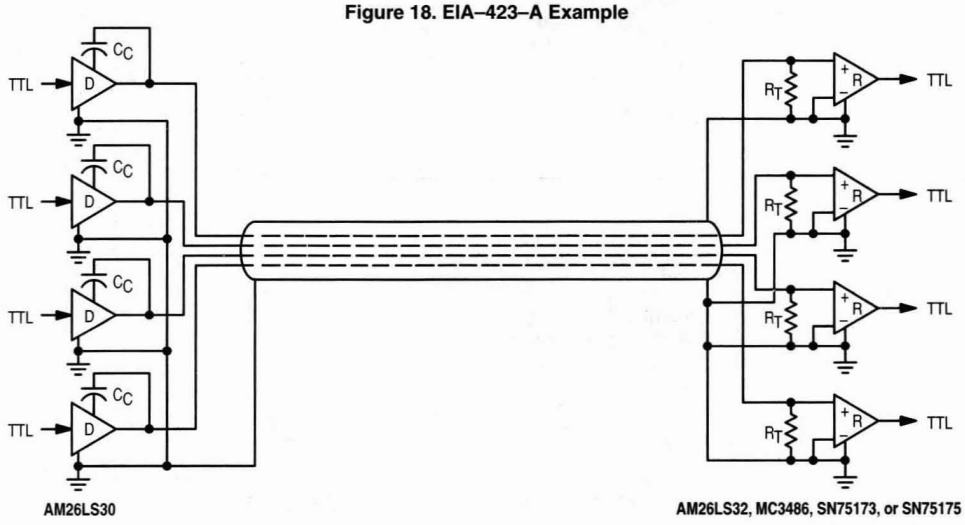
Leaving off the terminations will generally result in reflections which can have amplitudes of several volts above $V_{CC}$ or several volts below ground or $V_{EE}$. These overshoots/undershoots can disrupt the driver and/or receiver, create false data, and in some cases, damage components on the bus.

**Figure 17. EIA–422–A Example**




**NOTES:** 1. Terminating resistors $R_T$ should be located at the physical ends of the cable.
2. Stubs should be as short as possible.
3. Receivers = AM26LS32, MC3486, SN75173 or SN75175.
4. Circuit grounds must be connected together through a dedicated wire.

**Figure 18. EIA–423–A Example**



MOTOROLA

# AM26LS31

# Quad Line Driver with NAND Enabled Three-State Outputs

**QUAD EIA–422 LINE DRIVER WITH THREE–STATE OUTPUTS**

**SEMICONDUCTOR TECHNICAL DATA**

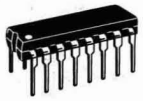
The Motorola AM26LS31 is a quad differential line driver intended for digital data transmission over balanced lines. It meets all the requirements of EIA–422 Standard and Federal Standard 1020.

The AM26LS31 provides an enable/disable function common to all four drivers as opposed to the split enables on the MC3487 EIA–422 driver.

The high impedance output state is assured during power down.

- Full EIA–422 Standard Compliance
- Single +5.0 V Supply
- Meets Full $V_O$ = 6.0 V, $V_{CC}$ = 0 V, $I_O$ < 100 μA Requirement
- Output Short Circuit Protection
- Complementary Outputs for Balanced Line Operation
- High Output Drive Capability
- Advanced LS Processing
- PNP Inputs for MOS Compatibility

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

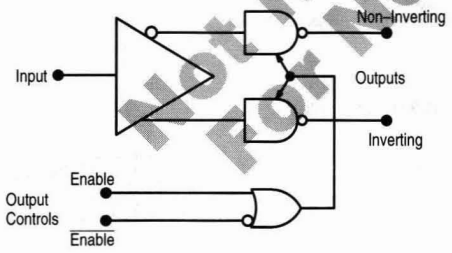


**PC SUFFIX**
PLASTIC PACKAGE
CASE 648

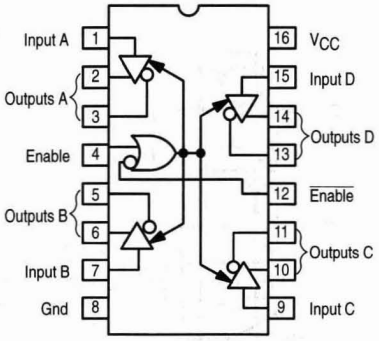
Not Recommended For New Design

7

**Representative Block Diagrams**




**PIN CONNECTIONS**




**TRUTH TABLE**

| Input | Control Inputs (E/$\overline{E}$) | Non–Inverting Output | Inverting Output |
|---|---|---|---|
| H | H/L | H | L |
| L | H/L | L | H |
| X | L/H | Z | Z |

L = Low Logic State
H = High Logic State
X = Irrelevant
Z = Third–State (High Impedance)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| AM26LS31PC | $T_A$ = 0 to +70°C | Plastic DIP |
| MC26LS31D* | | SO–16 |

* Note that the surface mount MC26LS31D device uses the same die as in the plastic DIP AM26LS31DC device, but with an MC prefix to prevent confusion with the package suffix.

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 8.0 | Vdc |
| Input Voltage | $V_I$ | 5.5 | Vdc |
| Operating Ambient Temperature Range | $T_A$ | 0 to + 70 | °C |
| Operating Junction Temperature Range | $T_J$ | 150 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, specifications apply 4.75 V ≤ $V_{CC}$ ≤ 5.25 V and 0°C ≤ $T_A$ ≤ 70°C. Typical values measured at $V_{CC}$ = 5.0 V, and $T_A$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Voltage – Low Logic State | $V_{IL}$ | – | – | 0.8 | Vdc |
| Input Voltage – High Logic State | $V_{IH}$ | 2.0 | – | – | Vdc |
| Input Current – Low Logic State ($V_{IL}$ = 0.4 V) | $I_{IL}$ | – | – | – 360 | µA |
| Input Current – High Logic State ($V_{IH}$ = 2.7 V) ($V_{IH}$ = 7.0 V) | $I_{IH}$ | –<br>– | –<br>– | + 20<br>+ 100 | µA |
| Input Clamp Voltage ($I_{IK}$ = – 18 mA) | $V_{IK}$ | – | – | – 1.5 | V |
| Output Voltage – Low Logic State ($I_{OL}$ = 20 mA) | $V_{OL}$ | – | – | 0.5 | V |
| Output Voltage – High Logic State ($I_{OH}$ = –20 mA) | $V_{OH}$ | 2.5 | – | – | V |
| Output Short Circuit Current ($V_{IH}$ = 2.0 V) Note 1 | $I_{OS}$ | – 30 | – | – 150 | mA |
| Output Leakage Current – Hi–Z State ($V_{OL}$ = 0.5 V, $V_{IL(E)}$ = 0.8 V, $V_{IH(\overline{E})}$ = 2.0 V) ($V_{OH}$ = 2.5 V, $V_{IL(E)}$ = 0.8 V, $V_{IH(E)}$ = 2.0 V) | $I_{O(Z)}$ | –<br>– | –<br>– | – 20<br>+ 20 | µA |
| Output Leakage Current – Power OFF ($V_{OH}$ = 6.0 V, $V_{CC}$ = 0 V) ($V_{OL}$ = – 0.25 V, $V_{CC}$ = 0 V) | $I_{O(off)}$ | –<br>– | –<br>– | + 100<br>– 100 | µA |
| Output Offset Voltage Difference, Note 2 | $V_{OS} - \overline{V}_{OS}$ | – | – | ± 0.4 | V |
| Output Differential Voltage, Note 2 | $V_{OD}$ | 2.0 | – | – | V |
| Output Differential Voltage Difference, Note 2 | $\lvert\Delta V_{OD}\rvert$ | – | – | ± 0.4 | V |
| Power Supply Current (Output Disabled) Note 3 | $I_{CCX}$ | – | 60 | 80 | mA |

**NOTES:** 1. Only one output may be shorted at a time.
2. See EIA Specification EIA–422 for exact test conditions.
3. Circuit in three–state condition.

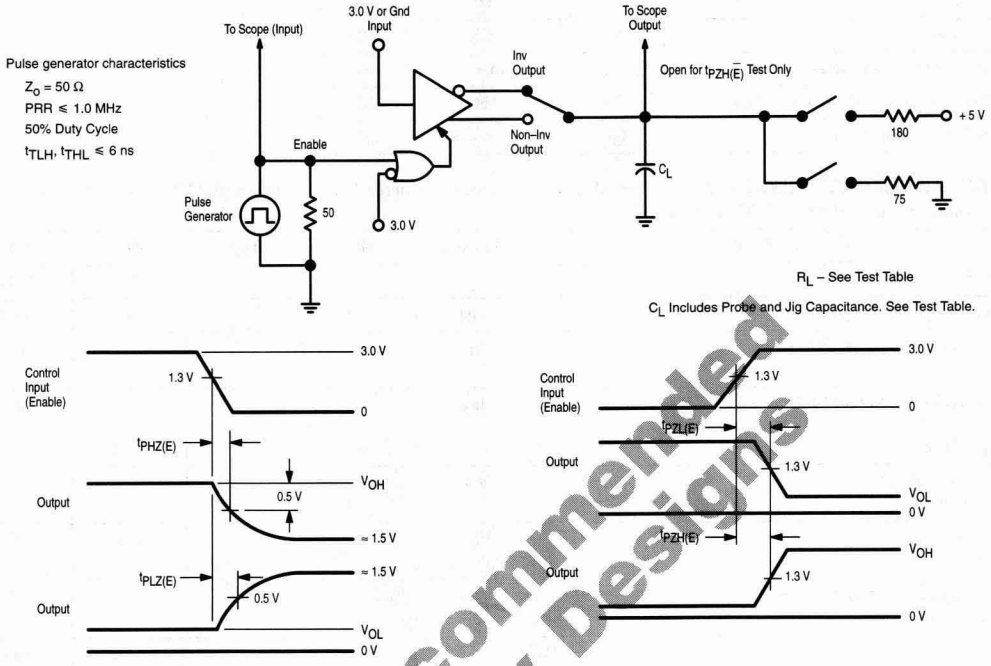
**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $T_A$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Times<br>High to Low Output<br>Low to High Output | <br>$t_{PHL}$<br>$t_{PLH}$ | <br>–<br>– | <br>–<br>– | <br>20<br>20 | ns |
| Output Skew | | – | – | 6.0 | ns |
| Propagation Delay – Control to Output<br>($C_L$ = 10 pF, $R_L$ = 75 Ω to Gnd)<br>($C_L$ = 10 pF, $R_L$ = 180 Ω to $V_{CC}$)<br>($C_L$ = 30 pF, $R_L$ = 75 Ω to Gnd)<br>($C_L$ = 30 pF, $R_L$ = 180 Ω to $V_{CC}$) | <br>$t_{PHZ(E)}$<br>$t_{PLZ(E)}$<br>$t_{PZH(E)}$<br>$t_{PZL(E)}$ | <br>–<br>–<br>–<br>– | <br>–<br>–<br>–<br>– | <br>30<br>35<br>40<br>45 | ns |

Not Recommended For New Designs

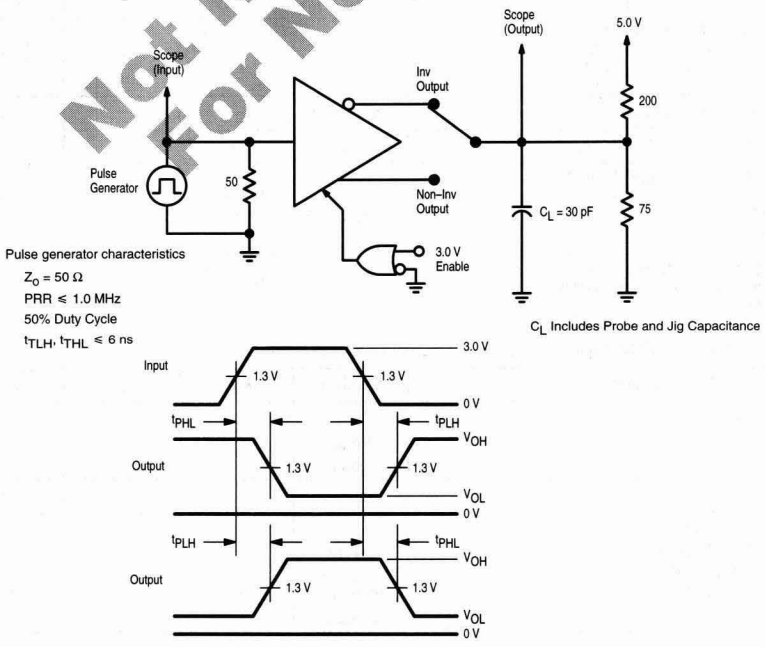
7

**Figure 1. Three–State Enable Test Circuit and Waveforms**




Not Recommended For New Designs

**Figure 2. Propagation Delay Times Input to Output Waveforms and Test Circuit**



MOTOROLA

# QUAD EIA-422/423 Line Receiver with Three-State Outputs

**AM26LS32**

**QUAD EIA–422/3 LINE RECEIVER WITH THREE–STATE OUTPUTS**

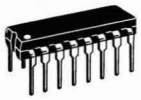
**SEMICONDUCTOR TECHNICAL DATA**

Motorola's Quad EIA–422/3 Receiver features four independent receiver chains which comply with EIA Standards for the Electrical Characteristics of Balanced/Unbalanced Voltage Digital Interface Circuits. Receiver outputs are 74LS compatible, three–state structures which are forced to a high impedance state when Pin 4 is a Logic "0" and Pin 12 is a Logic "1." A PNP device buffers each output control pin to assure minimum loading for either Logic "1" or Logic "0" inputs. In addition, each receiver chain has internal hysteresis circuitry to improve noise margin and discourage output instability for slowly changing input waveforms. A summary of AM26LS32 features include:

- Four Independent Receiver Chains
- Three–State Outputs
- High Impedance Output Control Inputs (PIA Compatible)
- Internal Hysteresis – 30 mV (Typical) @ Zero Volts Common Mode
- Fast Propagation Times – 25 ns (Typical)
- TTL Compatible
- Single 5.0 V Supply Voltage
- Fail–Safe Input–Output Relationship. Output Always High When Inputs Are Open, Terminated or Shorted
- 6.0 k Minimum Input Impedance

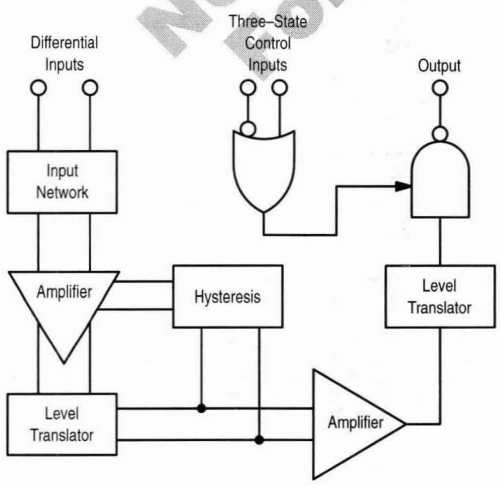
Not Recommended For New Design

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

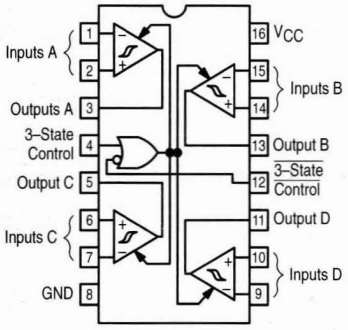


**PC SUFFIX**
PLASTIC PACKAGE
CASE 648

**Representative Block Diagram**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| AM26LS32PC | $T_A$ = 0 to 70°C | Plastic DIP |
| MC26LS32D* | | SO–16 |

* Note that the surface mount MC26LS32D device uses the same die as in the plastic DIP AM26LS32DC device, but with an MC prefix to prevent confusion with the package suffix.

7

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 | Vdc |
| Input Common Mode Voltage | $V_{ICM}$ | ± 25 | Vdc |
| Input Differential Voltage | $V_{ID}$ | ± 25 | Vdc |
| Three–State Control Input Voltage | $V_I$ | 7.0 | Vdc |
| Output Sink Current | $I_O$ | 50 | mA |
| Storage Temperature | $T_{stg}$ | – 65 to + 150 | °C |
| Operating Junction Temperature | $T_J$ | + 150 | °C |

## RECOMMENDED OPERATING CONDITIONS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.75 to 5.25 | Vdc |
| Operating Ambient Temperature | $T_A$ | 0 to + 70 | °C |
| Input Common Mode Voltage Range | $V_{ICR}$ | – 7.0 to + 7.0 | Vdc |
| Input Differential Voltage Range | $V_{IDR}$ | 6.0 | Vdc |

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, minimum and maximum limits apply over recommended temperature and power supply voltage ranges. Typical values are for $T_A$ = 25°C, $V_{CC}$ = 5.0 V and $V_{IC}$ = 0 V. See Note 1.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Voltage – High Logic State (Three–State Control) | $V_{IH}$ | 2.0 | – | – | V |
| Input Voltage – Low Logic State (Three–State Control) | $V_{IL}$ | | – | 0.8 | V |
| Differential Input Threshold Voltage (Note 2)<br>(–7.0 V ≤ $V_{IC}$ ≤ 7.0 V, $V_{IH}$ = 2.0 V)<br>($I_O$ = –0.4 mA, $V_{OH}$ ≥ 2.7 V)<br>($I_O$ = 8.0 mA, $V_{OL}$ ≤ 0.45 V) | $V_{TH(D)}$ | <br><br>–<br>– | <br><br>–<br>– | <br><br>0.2<br>–0.2 | V |
| Input Bias Current<br>($V_{CC}$ = 0 V or 5.25) (Other Inputs at –15 V ≤ $V_{in}$ ≤ +15 V)<br>$V_{in}$ = +15 V<br>$V_{in}$ = –15 V | $I_{IB(D)}$ | <br><br>–<br>– | <br><br>–<br>– | <br><br>2.3<br>–2.8 | mA |
| Input Resistance ( –15 V ≤ $V_{in}$ ≤ +15 V) | $R_{in}$ | 6.0 K | – | – | Ohms |
| Input Balance and Output Level<br>(–7.0 V ≤ $V_{IC}$ ≤ 7.0 V, $V_{IH}$ = 2.0 V, See Note 3)<br>($I_O$ = –0.4 mA, $V_{ID}$ = 0.4 V)<br>($I_O$ = 8.0 mA, $V_{ID}$ = –0.4 V) | <br>$V_{OH}$<br>$V_{OL}$ | <br>2.7<br>– | <br>–<br>– | <br>–<br>0.45 | V |
| Output Third State Leakage Current<br>($V_{I(D)}$ = + 3.0 V, $V_{IL}$ = 0.8 V, $V_O$ = 0.4 V)<br>($V_{I(D)}$ = – 3.0 V, $V_{IL}$ = 0.8 V, $V_O$ = 2.4 V) | $I_{OZ}$ | <br>–<br>– | <br>–<br>– | <br>–20<br>20 | µA |
| Output Short Circuit Current<br>($V_{I(D)}$ = 3.0 V, $V_{IH}$ = 2.0 V, $V_O$ = 0 V, See Note 4) | $I_{OS}$ | –15 | – | –85 | mA |
| Input Current – Low Logic State (Three–State Control)<br>($V_{IL}$ = 0.4 V) | $I_{IL}$ | – | – | –360 | µA |
| Input Current – High Logic State (Three–State Control)<br>($V_{IH}$ = 2.7 V)<br>($V_{IH}$ = 5.5 V) | $I_{IH}$ | <br>–<br>– | <br>–<br>– | <br>20<br>100 | µA |
| Input Clamp Diode Voltage (Three–State Control)<br>($I_{IC}$ = –18 mA) | $V_{IK}$ | – | – | –1.5 | V |
| Power Supply Current ($V_{IL}$ = 0 V) (All Inputs Grounded) | $I_{CC}$ | – | – | 70 | mA |

**NOTES:** 1. All currents into device pins are shown as positive, out of device pins are negative. All voltages referenced to ground unless otherwise noted.
2. Differential input threshold voltage and guaranteed output levels are done simultaneously for worst case.
3. Refer to EIA–422/3 for exact conditions. Input balance and guaranteed output levels are done simultaneously for worst case.
4. Only one output at a time should be shorted.

Not Recommended For New Designs

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 V and $T_A$ = 25°C, unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time – Differential Inputs to Output | | | | | ns |
| (Output High to Low) | $t_{PHL(D)}$ | – | – | 30 | |
| (Output Low to High) | $t_{PLH(D)}$ | – | – | 30 | |
| Propagation Delay Time – Three–State Control to Output | | | | | ns |
| (Output Low to Third State) | $t_{PLZ}$ | – | – | 35 | |
| (Output High to Third State) | $t_{PHZ}$ | – | – | 35 | |
| (Output Third State to High) | $t_{PZH}$ | – | – | 30 | |
| (Output Third State to Low) | $t_{PZL}$ | – | – | 30 | |

**Figure 1. Switching Test Circuit and Wave for Propagation Delay Differential Input to Output**

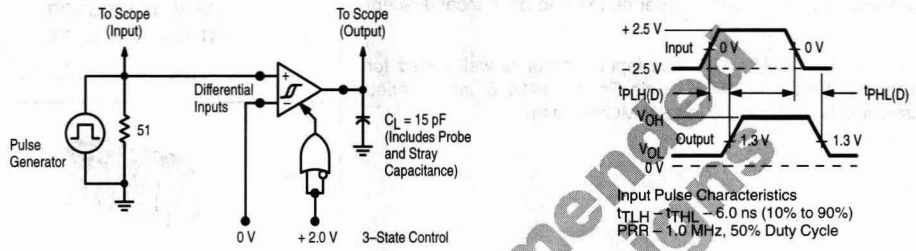
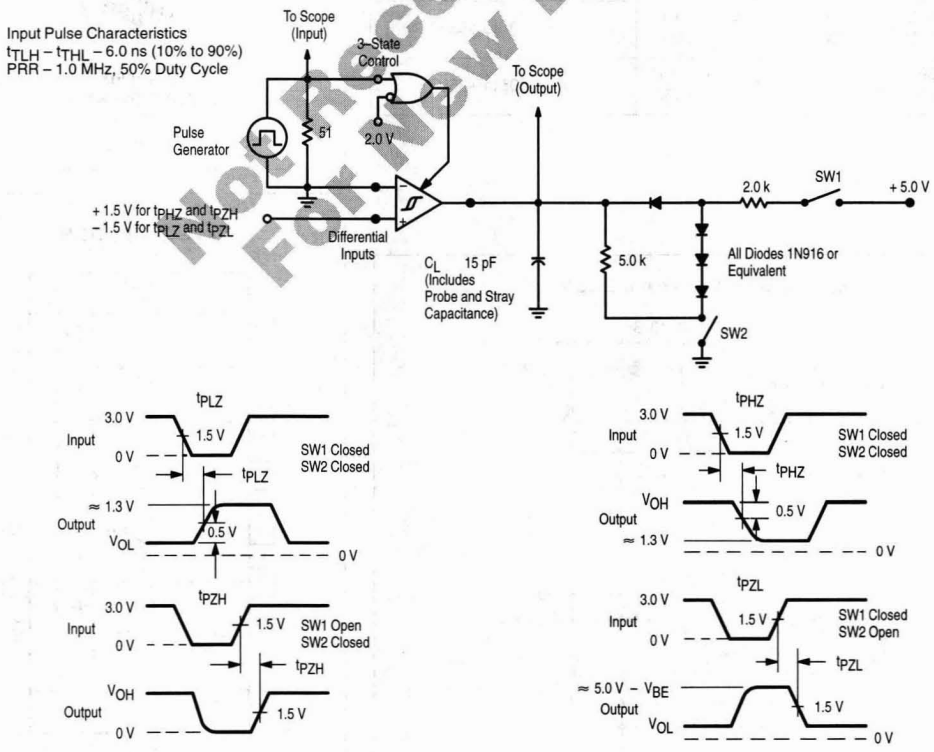



**Figure 2. Propagation Delay Three–State Control Input to Output**




Not Recommended For New Designs

7

MOTOROLA

# MC1413, B
# MC1416, B

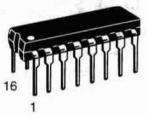
## High Voltage, High Current Darlington Transistor Arrays

The seven NPN Darlington connected transistors in these arrays are well suited for driving lamps, relays, or printer hammers in a variety of industrial and consumer applications. Their high breakdown voltage and internal suppression diodes insure freedom from problems associated with inductive loads. Peak inrush currents to 500 mA permit them to drive incandescent lamps.

The MC1413, B with a 2.7 kΩ series input resistor is well suited for systems utilizing a 5.0 V TTL or CMOS Logic. The MC1416, B uses a series 10.5 kΩ resistor and is useful in 8.0 to 18 V MOS systems.

**PERIPHERAL DRIVER ARRAYS**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 648

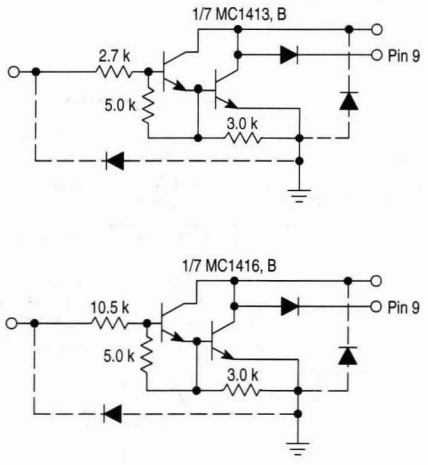
**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

7

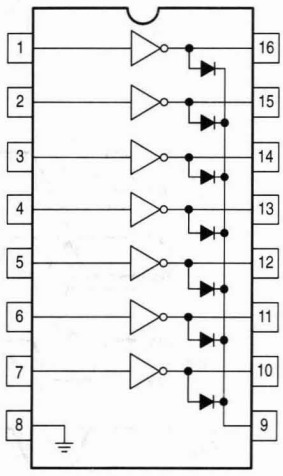
**ORDERING INFORMATION**

| Plastic DIP | SOIC | Operating Temperature Range |
|---|---|---|
| MC1413P (ULN2003A)<br>MC1416P (ULN2004A) | MC1413D<br>MC1416D | $T_A$ = –20° to +85°C |
| MC1413BP<br>MC1416BP | MC1413BD<br>MC1416BD | $T_A$ = –40° to +85°C |

**Representative Schematic Diagrams**




**PIN CONNECTIONS**




(Top View)

**MAXIMUM RATINGS** ($T_A$ = 25°C, and rating apply to any one device in the package, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Output Voltage | $V_O$ | 50 | V |
| Input Voltage | $V_I$ | 30 | V |
| Collector Current – Continuous | $I_C$ | 500 | mA |
| Base Current – Continuous | $I_B$ | 25 | mA |
| Operating Ambient Temperature Range<br>MC1413–16<br>MC1413B–16B | $T_A$ | <br>–20 to +85<br>–40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +150 | °C |
| Junction Temperature | $T_J$ | 150 | °C |
| Thermal Resistance, Junction–to–Ambient<br>Case 648, P Suffix<br>Case 751B, D Suffix | $\theta_{JA}$ | <br>67<br>100 | °C/W |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Output Leakage Current | | $I_{CEX}$ | | | | µA |
| ($V_O$ = 50 V, $T_A$ = +85°C) | All Types | | – | – | 100 | |
| ($V_O$ = 50 V, $T_A$ = +25°C) | All Types | | – | – | 50 | |
| ($V_O$ = 50 V, $T_A$ = +85°C, $V_I$ = 1.0 V) | MC1416, B | | – | – | 500 | |
| Collector–Emitter Saturation Voltage | | $V_{CE(sat)}$ | | | | V |
| ($I_C$ = 350 mA, $I_B$ = 500 µA) | All Types | | – | 1.1 | 1.6 | |
| ($I_C$ = 200 mA, $I_B$ = 350 µA) | All Types | | – | 0.95 | 1.3 | |
| ($I_C$ = 100 mA, $I_B$ = 250 µA) | All Types | | – | 0.85 | 1.1 | |
| Input Current – On Condition | | $I_{I(on)}$ | | | | mA |
| ($V_I$ = 3.85 V) | MC1413, B | | – | 0.93 | 1.35 | |
| ($V_I$ = 5.0 V) | MC1416, B | | – | 0.35 | 0.5 | |
| ($V_I$ = 12 V) | MC1416, B | | – | 1.0 | 1.45 | |
| Input Voltage – On Condition | | $V_{I(on)}$ | | | | V |
| ($V_{CE}$ = 2.0 V, $I_C$ = 200 mA) | MC1413, B | | – | – | 2.4 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 250 mA) | MC1413, B | | – | – | 2.7 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 300 mA) | MC1413, B | | – | – | 3.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 125 mA) | MC1416, B | | – | – | 5.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 200 mA) | MC1416, B | | – | – | 6.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 275 mA) | MC1416, B | | – | – | 7.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 350 mA) | MC1416, B | | – | – | 8.0 | |
| Input Current – Off Condition<br>($I_C$ = 500 µA, $T_A$ = 85°C) | All Types | $I_{I(off)}$ | 50 | 100 | – | µA |
| DC Current Gain<br>($V_{CE}$ = 2.0 V, $I_C$ = 350 mA) | | $h_{FE}$ | 1000 | – | – | – |
| Input Capacitance | | $C_I$ | – | 15 | 30 | pF |
| Turn–On Delay Time<br>(50% $E_I$ to 50% $E_O$) | | $t_{on}$ | – | 0.25 | 1.0 | µs |
| Turn–Off Delay Time<br>(50% $E_I$ to 50% $E_O$) | | $t_{off}$ | – | 0.25 | 1.0 | µs |
| Clamp Diode Leakage Current<br>($V_R$ = 50 V) | $T_A$ = +25°C<br>$T_A$ = +85°C | $I_R$ | –<br>– | –<br>– | 50<br>100 | µA |
| Clamp Diode Forward Voltage<br>($I_F$ = 350 mA) | | $V_F$ | – | 1.5 | 2.0 | V |

7

## TYPICAL PERFORMANCE CURVES – $T_A$ = 25°C

**Figure 1. Output Current versus Input Voltage**

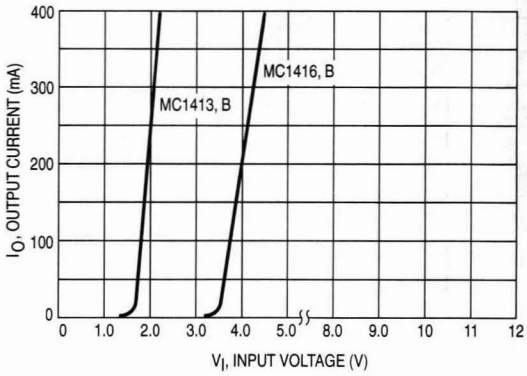



**Figure 2. Output Current versus Input Current**

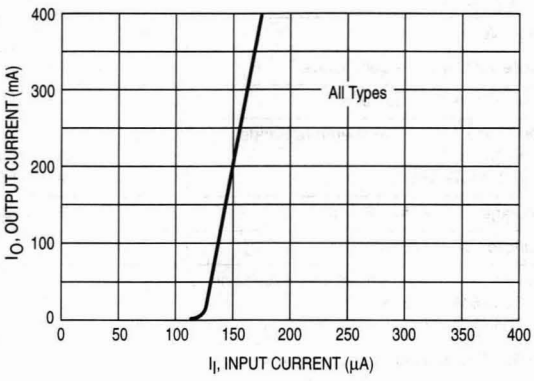



**Figure 3. Typical Output Characteristics**

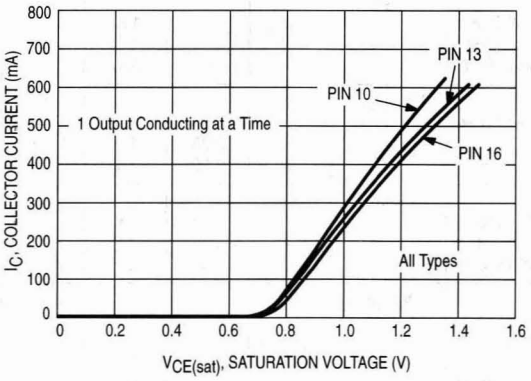



**Figure 4. Input Characteristics – MC1413, B**

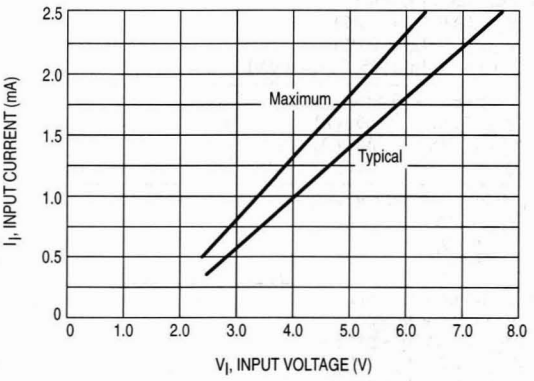



**Figure 5. Input Characteristics – MC1416, B**

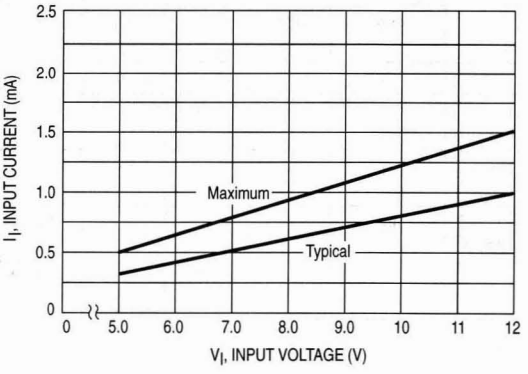
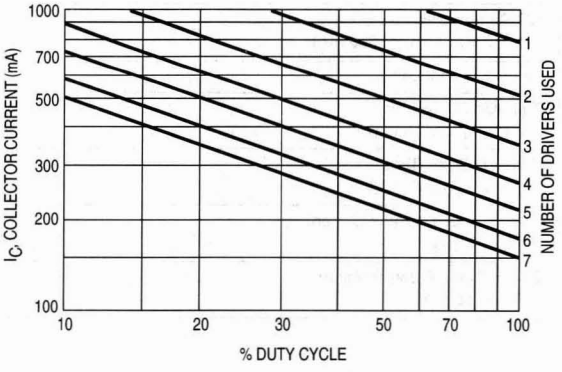



**Figure 6. Maximum Collector Current versus Duty Cycle (and Number of Drivers in Use)**



MOTOROLA

# MC1488

# Quad Line Driver

The MC1488 is a monolithic quad line driver designed to interface data terminal equipment with data communications equipment in conformance with the specifications of EIA Standard No. EIA–232D.

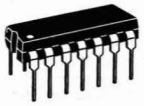
**Features:**

- Current Limited Output ±10 mA typical
- Power–Off Source Impedance 300 Ω mininum
- Simple Slew Rate Control with External Capacitor
- Flexible Operating Supply Range
- Compatible with All Motorola MDTL and MTTL Logic Families

**QUAD MDTL LINE DRIVER**
**EIA–232D**

**SEMICONDUCTOR TECHNICAL DATA**

**P SUFFIX**
PLASTIC PACKAGE
CASE 646

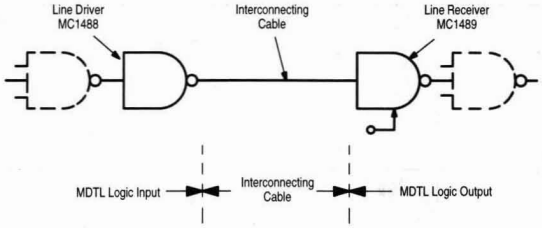


**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

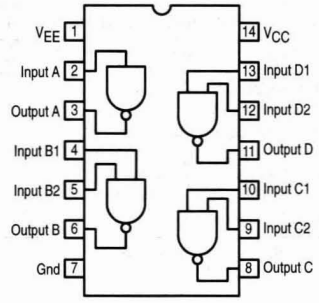
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1488P | $T_A$ = 0 to + 75°C | Plastic |
| MC1488D | | SO–14 |

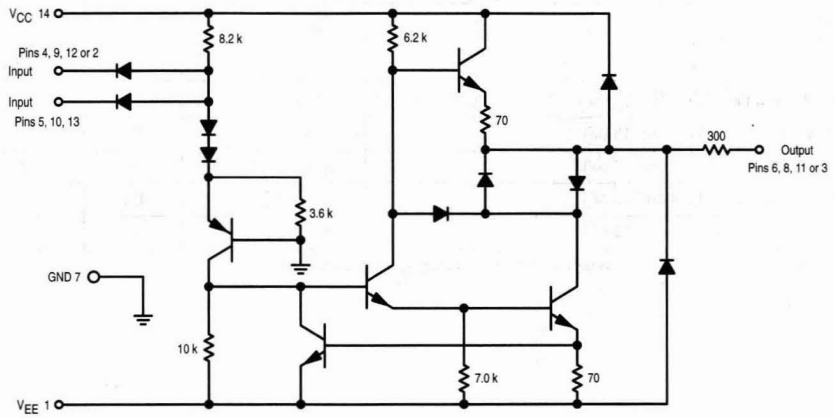
**Simplified Application**




**PIN CONNECTIONS**




**Circuit Schematic**
(1/4 of Circuit Shown)



**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$<br>$V_{EE}$ | + 15<br>– 15 | Vdc |
| Input Voltage Range | $V_{IR}$ | – 15 ≤ $V_{IR}$ ≤ 7.0 | Vdc |
| Output Signal Voltage | $V_O$ | ±15 | Vdc |
| Power Derating (Package Limitation, SO–14 and Plastic Dual–In–Line Package)<br>Derate above $T_A$ = + 25°C | $P_D$<br>$1/R_{\theta JA}$ | 1000<br>6.7 | mW<br>mW/°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to + 75 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 175 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = + 9.0 ± 1% Vdc, $V_{EE}$ = –9.0 ± 1% Vdc, $T_A$ = 0 to 75°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Current – Low Logic State ($V_{IL}$ = 0) | $I_{IL}$ | – | 1.0 | 1.6 | mA |
| Input Current – High Logic State ($V_{IH}$ = 5.0 V) | $I_{IH}$ | – | – | 10 | µA |
| Output Voltage – High Logic State<br>($V_{IL}$ = 0.8 Vdc, $R_L$ = 3.0 kΩ, $V_{CC}$ = + 9.0 Vdc, $V_{EE}$ = – 9.0 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $R_L$ = 3.0 kΩ, $V_{CC}$ = + 13.2 Vdc, $V_{EE}$ = – 13.2 Vdc) | $V_{OH}$ | <br>+ 6.0<br>+ 9.0 | <br>+7.0<br>+10.5 | <br>–<br>– | Vdc |
| Output Voltage – Low Logic State<br>($V_{IH}$ = 1.9 Vdc, $R_L$ = 3.0 kΩ, $V_{CC}$ = + 9.0 Vdc, $V_{EE}$ = – 9.0 Vdc)<br>($V_{IH}$ = 1.9 Vdc, $R_L$ = 3.0 kΩ, $V_{CC}$ = + 13.2 Vdc, $V_{EE}$ = – 13.2 Vdc) | $V_{OL}$ | <br>– 6.0<br>– 9.0 | <br>– 7.0<br>– 10.5 | <br>–<br>– | Vdc |
| Positive Output Short–Circuit Current, Note 1 | $I_{OS+}$ | + 6.0 | + 10 | + 12 | mA |
| Negative Output Short–Circuit Current, Note 1 | $I_{OS-}$ | – 6.0 | – 10 | – 12 | mA |
| Output Resistance ($V_{CC}$ = $V_{EE}$ = 0, $\|V_O\|$ = ± 2.0 V) | $r_o$ | 300 | – | – | Ohms |
| Positive Supply Current ($R_I$ = ∞)<br>($V_{IH}$ = 1.9 Vdc, $V_{CC}$ = + 9.0 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{CC}$ = + 9.0 Vdc)<br>($V_{IH}$ = 1.9 Vdc, $V_{CC}$ = + 12 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{CC}$ = + 12 Vdc)<br>($V_{IH}$ = 1.9 Vdc, $V_{CC}$ = + 15 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{CC}$ = + 15 Vdc) | $I_{CC}$ | <br>–<br>–<br>–<br>–<br>–<br>– | <br>+ 15<br>+ 4.5<br>+ 19<br>+ 5.5<br>–<br>– | <br>+ 20<br>+ 6.0<br>+ 25<br>+ 7.0<br>+ 34<br>+ 12 | mA |
| Negative Supply Current ($R_L$ = ∞)<br>($V_{IH}$ = 1.9 Vdc, $V_{EE}$ = – 9.0 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{EE}$ = – 9.0 Vdc)<br>($V_{IH}$ = 1.9 Vdc, $V_{EE}$ = – 12 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{EE}$ = – 12 Vdc)<br>($V_{IH}$ = 1.9 Vdc, $V_{EE}$ = – 15 Vdc)<br>($V_{IL}$ = 0.8 Vdc, $V_{EE}$ = – 15 Vdc) | $I_{EE}$ | <br>–<br>–<br>–<br>–<br>–<br>– | <br>– 13<br>–<br>– 18<br>–<br>–<br>– | <br>– 17<br>– 500<br>– 23<br>– 500<br>– 34<br>– 2.5 | <br>mA<br>µA<br>mA<br>µA<br>mA<br>mA |
| Power Consumption<br>($V_{CC}$ = 9.0 Vdc, $V_{EE}$ = – 9.0 Vdc)<br>($V_{CC}$ = 12 Vdc, $V_{EE}$ = – 12 Vdc) | $P_C$ | <br>–<br>– | <br>–<br>– | <br>333<br>576 | mW |

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = +9.0 ± 1% Vdc, $V_{EE}$ = –9.0 ± 1% Vdc, $T_A$ = +25°C.)

| | | | | | | |
|---|---|---|---|---|---|---|
| Propagation Delay Time | ($z_l$ = 3.0 k and 15 pF) | $t_{PLH}$ | – | 275 | 350 | ns |
| Fall Time | ($z_l$ = 3.0 k and 15 pF) | $t_{THL}$ | – | 45 | 75 | ns |
| Propagation Delay Time | ($z_l$ = 3.0 k and 15 pF) | $t_{PHL}$ | – | 110 | 175 | ns |
| Rise Time | ($z_l$ = 3.0 k and 15 pF) | $t_{TLH}$ | – | 55 | 100 | ns |

**NOTE:** 1. Maximum Package Power Dissipation may be exceeded if all outputs are shorted simultaneously.

## CHARACTERISTIC DEFINITIONS

**Figure 1. Input Current**

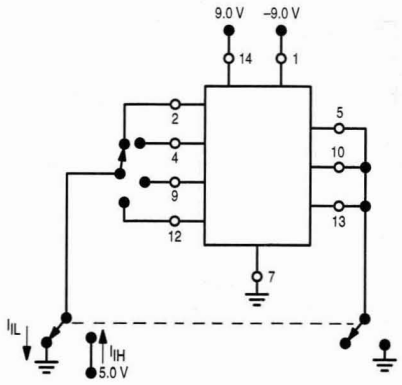



**Figure 2. Output Voltage**

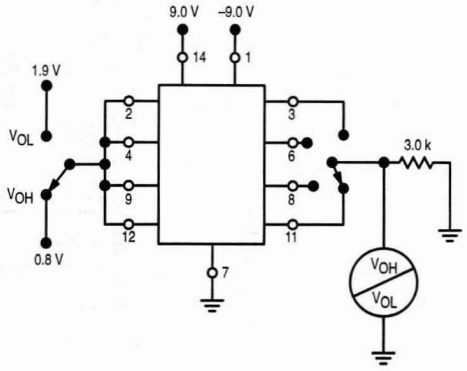



**Figure 3. Output Short–Circuit Current**

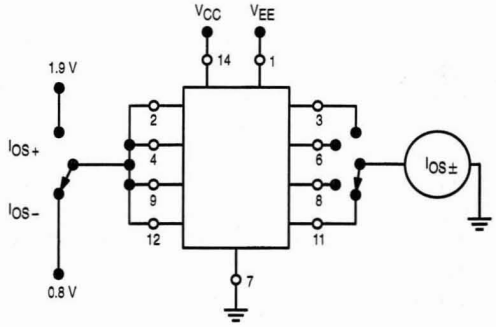



**Figure 4. Output Resistance (Power Off)**

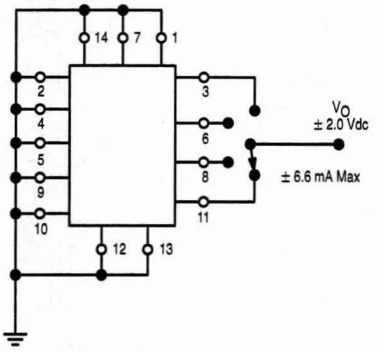



**Figure 5. Power Supply Currents**

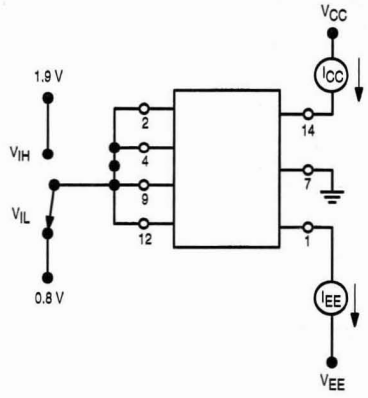
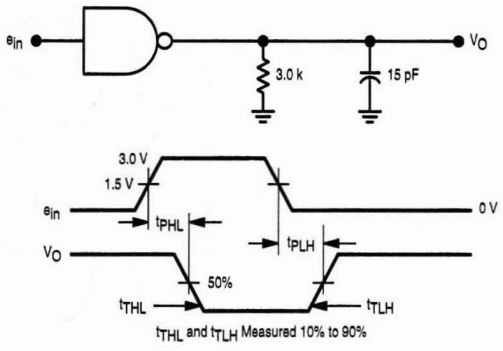



**Figure 6. Switching Response**

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## TYPICAL CHARACTERISTICS

($T_A$ = +25°C, unless otherwise noted.)

**Figure 7. Transfer Characteristics versus Power Supply Voltage**

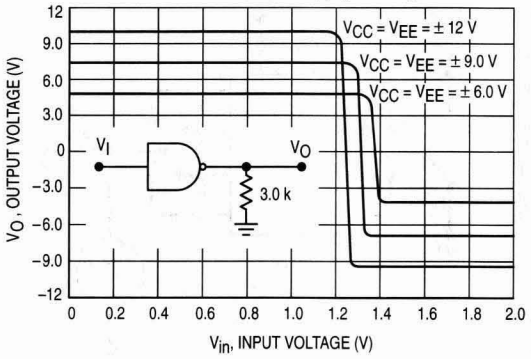
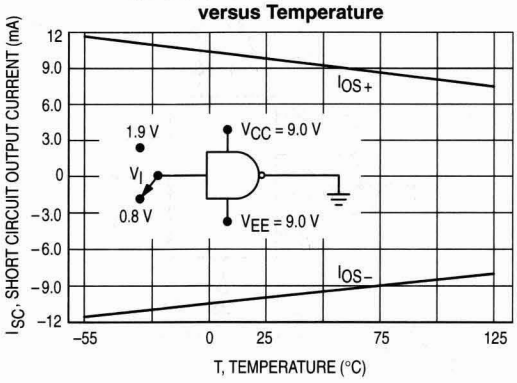



**Figure 8. Short Circuit Output Current versus Temperature**




7

**Figure 9. Output Slew Rate versus Load Capacitance**

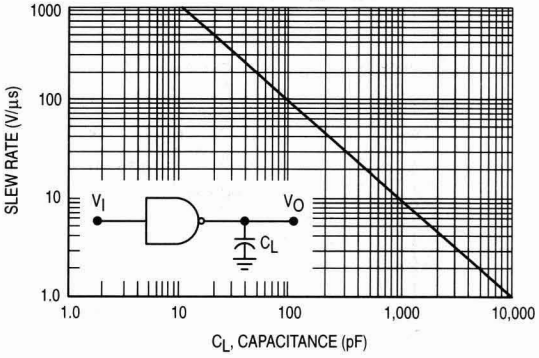



**Figure 10. Output Voltage and Current–Limiting Characteristics**

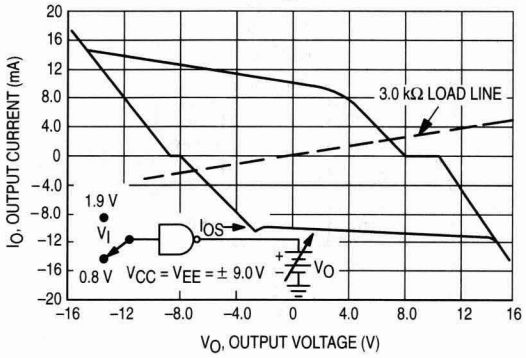
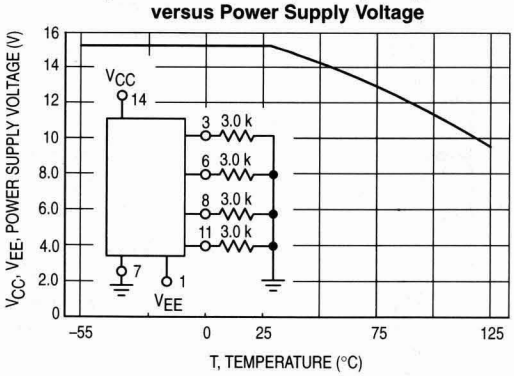



**Figure 11. Maximum Operating Temperature versus Power Supply Voltage**



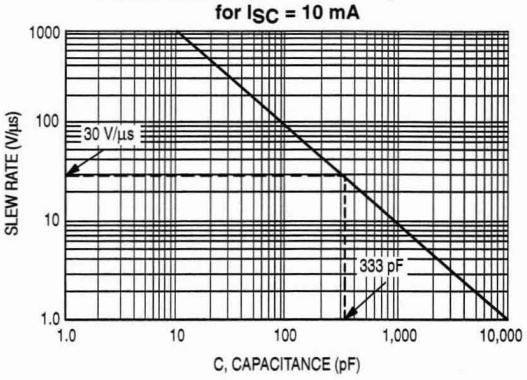
## APPLICATIONS INFORMATION

The Electronic Industries Association EIA–232D specification details the requirements for the interface between data processing equipment and data communications equipment. This standard specifies not only the number and type of interface leads, but also the voltage levels to be used. The MC1488 quad driver and its companion circuit, the MC1489 quad receiver, provide a complete interface system between DTL or TTL logic levels and the EIA–232D defined levels. The EIA–232D requirements as applied to drivers are discussed herein.

The required driver voltages are defined as between 5.0 and 15 V in magnitude and are positive for a Logic "0" and negative for a Logic "1." These voltages are so defined when the drivers are terminated with a 3000 to 7000 Ω resistor. The MC1488 meets this voltage requirement by converting a DTL/TTL logic level into EIA–232D levels with one stage of inversion.

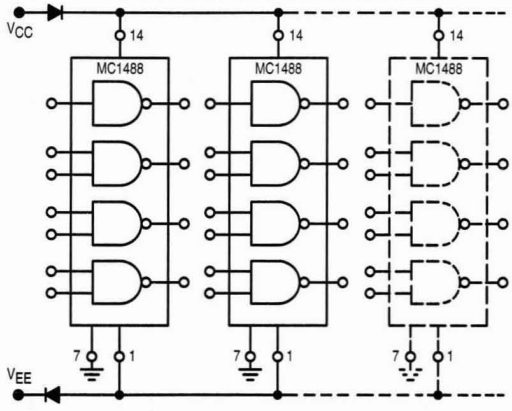
The EIA–232D specification further requires that during transitions, the driver output slew rate must not exceed 30 V per microsecond. The inherent slew rate of the MC1488 is much too fast for this requirement. The current limited output of the device can be used to control this slew rate by connecting a capacitor to each driver output. The required capacitor can be easily determined by using the relationship $C = I_{OS} \times \Delta T/\Delta V$ from which Figure 12 is derived. Accordingly, a 330 pF capacitor on each output will guarantee a worst case slew rate of 30 V per microsecond.

**Figure 12. Slew Rate versus Capacitance for $I_{SC}$ = 10 mA**




The interface driver is also required to withstand an accidental short to any other conductor in an interconnecting cable. The worst possible signal on any conductor would be another driver using a plus or minus 15 V, 500 mA source. The MC1488 is designed to indefinitely withstand such a short to all four outputs in a package as long as the power supply voltages are greater than 9.0 V (i.e., $V_{CC} \geq 9.0$ V; $V_{EE} \leq -9.0$ V). In some power supply designs, a loss of system power causes a low impedance on the power supply outputs. When this occurs, a low impedance to ground would exist at the power inputs to the MC1488 effectively shorting the 300 Ω output resistors to ground. If all four outputs were then shorted to plus or minus 15 V, the power dissipation in these resistors would be excessive. Therefore, if the system is designed to permit low impedances to ground at the power supplies of the drivers, a diode should be placed in each power supply lead to prevent overheating in this fault condition. These two diodes, as shown in Figure 13, could be used to decouple all the driver packages in a system. (These same diodes will allow the MC1488 to withstand momentary shorts to the ± 25 V limits specified in the earlier Standard EIA–232B.) The addition of the diodes also permits the MC1488 to withstand faults with power supplies of less than the 9.0 V stated above.

**Figure 13. Power Supply Protection to Meet Power Off Fault Conditions**




The maximum short circuit current allowable under fault conditions is more than guaranteed by the previously mentioned 10 mA output current limiting.

### Other Applications

The MC1488 is an extremely versatile line driver with a myriad of possible applications. Several features of the drivers enhance this versatility:

1. Output Current Limiting – this enables the circuit designer to define the output voltage levels independent of power supplies and can be accomplished by diode clamping of the output pins. Figure 14 shows the MC1488 used as a DTL to MOS translator where the high level voltage output is clamped one diode above ground. The resistor divider shown is used to reduce the output voltage below the 300 mV above ground MOS input level limit.

2. Power Supply Range – as can be seen from the schematic drawing of the drivers, the positive and negative driving elements of the device are essentially independent and do not require matching power supplies. In fact, the positive supply can vary from a minimum 7.0 V (required for driving the negative pulldown section) to the maximum specified 15 V. The negative supply can vary from approximately – 2.5 V to the minimum specified – 15 V. The MC1488 will drive the output to within 2.0 V of the positive or negative supplies as long as the current output limits are not exceeded. The combination of the current limiting and supply voltage features allow a wide combination of possible outputs within the same quad package. Thus if only a portion of the four drivers are used for driving EIA–232D lines, the remainder could be used for DTL to MOS or even DTL to DTL translation. Figure 15 shows one such combination.

**Figure 14. MDTL/MTTL–to–MOS Translator**

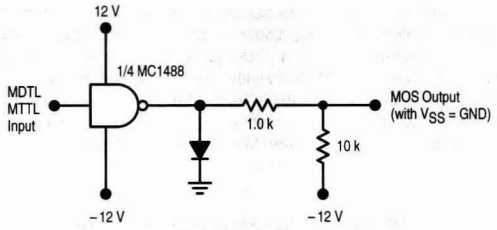
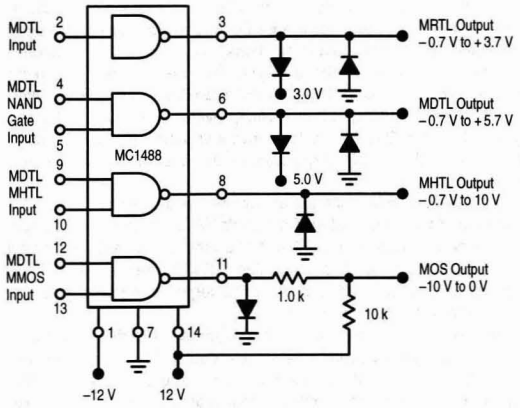



**Figure 15. Logic Translator Applications**




7

MOTOROLA

# Quad Line Receivers

The MC1489 monolithic quad line receivers are designed to interface data terminal equipment with data communications equipment in conformance with the specifications of EIA Standard No. EIA–232D.

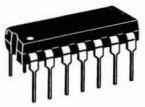
- Input Resistance – 3.0 k to 7.0 kΩ
- Input Signal Range – ± 30 V
- Input Threshold Hysteresis Built In
- Response Control
  a) Logic Threshold Shifting
  b) Input Noise Filtering

**MC1489, A**

**QUAD MDTL LINE RECEIVERS EIA–232D**

**SEMICONDUCTOR TECHNICAL DATA**

**P SUFFIX**
PLASTIC PACKAGE
CASE 646

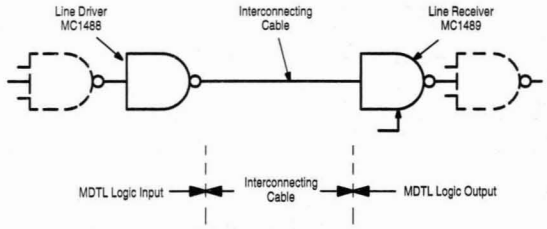


**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

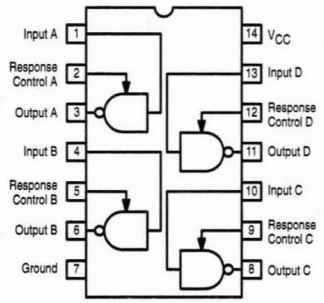
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1489P, AP | $T_A$ = 0 to + 75°C | Plastic |
| MC1489D, AD | | SO–14 |

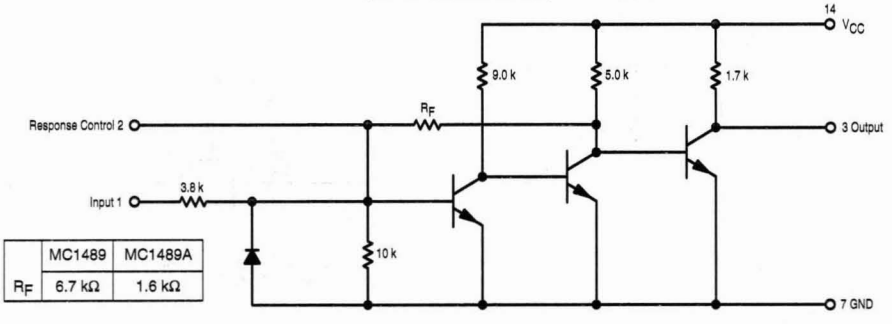
**Simplified Application**




**PIN CONNECTIONS**




**Representative Schematic Diagram**
(1/4 of Circuit Shown)




| | MC1489 | MC1489A |
|---|---|---|
| $R_F$ | 6.7 kΩ | 1.6 kΩ |

7

**MAXIMUM RATINGS** ($T_A$ = + 25°C, unless otherwise noted)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 10 | Vdc |
| Input Voltage Range | $V_{IR}$ | ± 30 | Vdc |
| Output Load Current | $I_L$ | 20 | mA |
| Power Dissipation (Package Limitation, SO–14 and Plastic Dual In–Line Package)<br>Derate above $T_A$ = + 25°C | $P_D$<br>$1/\theta JA$ | 1000<br>6.7 | mW<br>mW/°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to + 75 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 175 | °C |

**ELECTRICAL CHARACTERISTICS** (Response control pin is open.) ($V_{CC}$ = + 5.0 Vdc ± 10%, $T_A$ = 0 to + 75°C, unless otherwise noted)

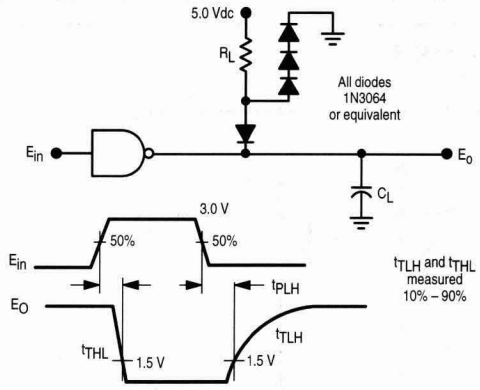
| Characteristics | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Positive Input Current | ($V_{IH}$ = + 25 Vdc)<br>($V_{IH}$ = + 3.0 Vdc) | $I_{IH}$ | 3.6<br>0.43 | –<br>– | 8.3<br>– | mA |
| Negative Input Current | ($V_{IH}$ = – 25 Vdc)<br>($V_{IH}$ = – 3.0 Vdc) | $I_{IL}$ | – 3.6<br>– 0.43 | –<br>– | – 8.3<br>– | mA |
| Input Turn–On Threshold Voltage<br>($T_A$ = + 25°C, $V_{OL}$ ≤ 0.45 V) | MC1489<br>MC1489A | $V_{IH}$ | <br>1.0<br>1.75 | <br>–<br>1.95 | <br>1.5<br>2.25 | Vdc |
| Input Turn–Off Threshold Voltage<br>($T_A$ = + 25°C, $V_{OH}$ ≥ 2.5 V, $I_L$ = – 0.5 mA) | MC1489<br>MC1489A | $V_{IL}$ | <br>0.75<br>0.75 | <br>–<br>0.8 | <br>1.25<br>1.25 | Vdc |
| Output Voltage High | ($V_{IH}$ = 0.75 V, $I_L$ = – 0.5 mA)<br>(Input Open Circuit, $I_L$ = – 0.5 mA) | $V_{OH}$ | 2.5<br>2.5 | 4.0<br>4.0 | 5.0<br>5.0 | Vdc |
| Output Voltage Low | ($V_{IL}$ = 3.0 V, $I_L$ = 10 mA) | $V_{OL}$ | – | 0.2 | 0.45 | Vdc |
| Output Short–Circuit Current | | $I_{OS}$ | – | – 3.0 | – 4.0 | mA |
| Power Supply Current (All Gates "on," $I_{out}$ = 0 mA, $V_{IH}$ = + 5.0 Vdc) | | $I_{CC}$ | – | 16 | 26 | mA |
| Power Consumption | ($V_{IH}$ = + 5.0 Vdc) | $P_C$ | – | 80 | 130 | mW |

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc ± 1%, $T_A$ = + 25°C, See Figure 1.)

| | | | | | | |
|---|---|---|---|---|---|---|
| Propagation Delay Time | ($R_L$ = 3.9 kΩ) | $t_{PLH}$ | – | 25 | 85 | ns |
| Rise Time | ($R_L$ = 3.9 kΩ) | $t_{TLH}$ | – | 120 | 175 | ns |
| Propagation Delay Time | ($R_L$ = 390 kΩ) | $t_{PHL}$ | – | 25 | 50 | ns |
| Fall Time | ($R_L$ = 390 kΩ) | $t_{THL}$ | – | 10 | 20 | ns |

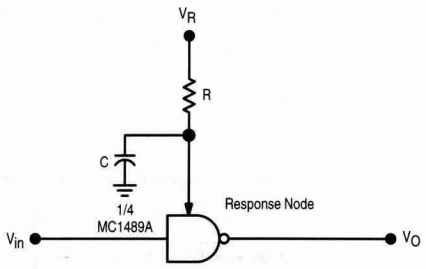
## TEST CIRCUITS

**Figure 1. Switching Response**




$C_L$ = 15 pF = total parasitic capacitance which includes probe and wiring capacitances

**Figure 2. Response Control Node**




C, capacitor is for noise filtering.
R, resistor is for threshold shifting.

## TYPICAL CHARACTERISTICS

($V_{CC}$ = 5.0 Vdc, $T_A$ = +25°C, unless otherwise noted)

**Figure 3. Input Current**

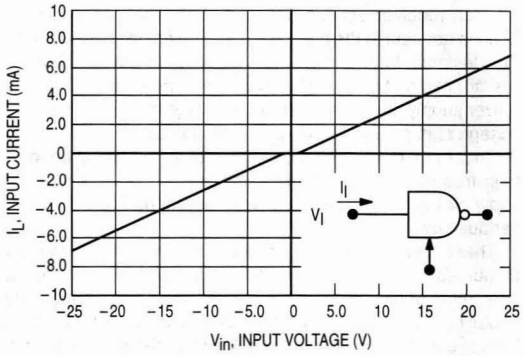



**Figure 4. MC1489 Input Threshold Voltage Adjustment**

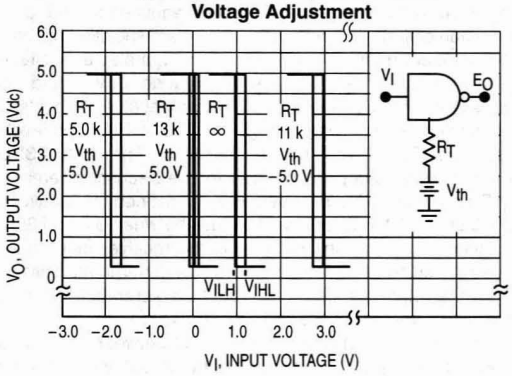



**Figure 5. MC1489A Input Threshold Voltage Adjustment**

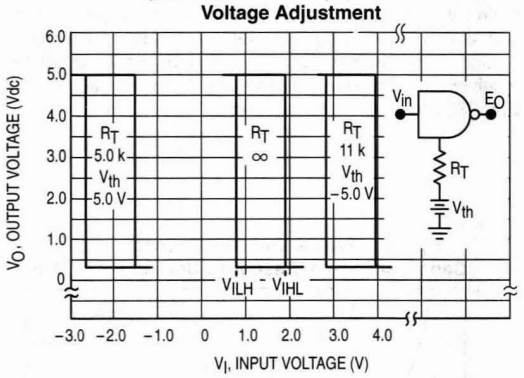



**Figure 6. Input Threshold Voltage versus Temperature**

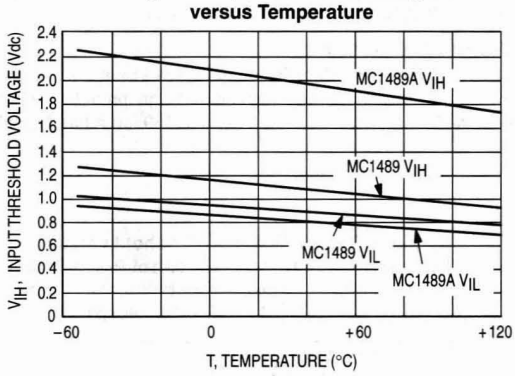
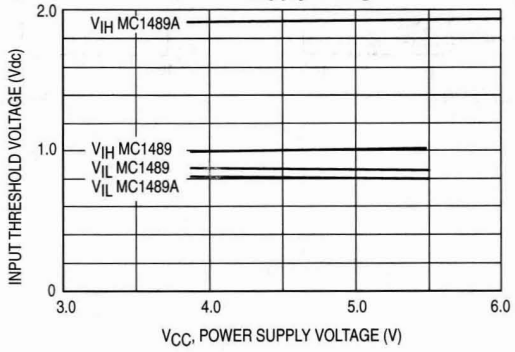



**Figure 7. Input Threshold versus Power Supply Voltage**



## APPLICATIONS INFORMATION

### General Information

The Electronic Industries Association (EIA) has released the EIA–232D specification detailing the requirements for the interface between data processing equipment and data communications equipment. This standard specifies not only the number and type of interface leads, but also the voltage levels to be used. The MC1488 quad driver and its companion circuit, the MC1489 quad receiver, provide a complete interface system between DTL or TTL logic levels and the EIA–232D defined levels. The EIA--232D requirements as applied to receivers are discussed herein.

The required input impedance is defined as between 3000 Ω and 7000 Ω for input voltages between 3.0 and 25 V in magnitude; and any voltage on the receiver input in an open circuit condition must be less than 2.0 V in magnitude. The MC1489 circuits meet these requirements with a maximum open circuit voltage of one $V_{BE}$.

The receiver shall detect a voltage between – 3.0 and – 25 V as a Logic "1" and inputs between 3.0 and 25 V as a Logic "0." On some interchange leads, an open circuit of power "OFF" condition (300 Ω or more to ground) shall be decoded as an "OFF" condition or Logic "1." For this reason, the input hysteresis thresholds of the MC1489 circuits are all above ground. Thus an open or grounded input will cause the same output as a negative or Logic "1" input.

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### Device Characteristics

The MC1489 interface receivers have internal feedback from the second stage to the input stage providing input hysteresis for noise rejection. The MC1489 input has typical turn–on voltage of 1.25 V and turn–off of 1.0 V for a typical hysteresis of 250 mV. The MC1489A has typical turn–on of 1.95 V and turn–off of 0.8 V for typically 1.15 V of hysteresis.

Each receiver section has an external response control node in addition to the input and output pins, thereby allowing the designer to vary the input threshold voltage levels. A resistor can be connected between this node and an external power supply. Figures 2, 4 and 5 illustrate the input threshold voltage shift possible through this technique.

This response node can also be used for the filtering of high frequency, high energy noise pulses. Figures 8 and 9 show typical noise pulse rejection for external capacitors of various sizes.

These two operations on the response node can be combined or used individually for many combinations of interfacing applications. The MC1489 circuits are particularly useful for interfacing between MOS circuits and MDTL/MTTL logic systems. In this application, the input threshold voltages are adjusted (with the appropriate supply and resistor values) to fall in the center of the MOS voltage logic levels (see Figure 10).

The response node may also be used as the receiver input as long as the designer realizes that he may not drive this node with a low impedance source to a voltage greater than one diode above ground or less than one diode below ground. This feature is demonstrated in Figure 11 where two receivers are slaved to the same line that must still meet the EIA–232D impedance requirement.

**Figure 8. Typical Turn On Threshold versus Capacitance from Response Control Pin to GND**

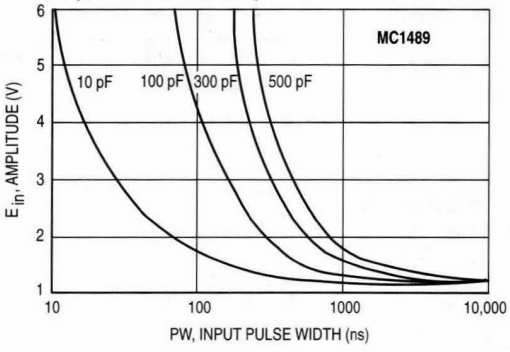



**Figure 9. Typical Turn On Threshold versus Capacitance from Response Control Pin to GND**

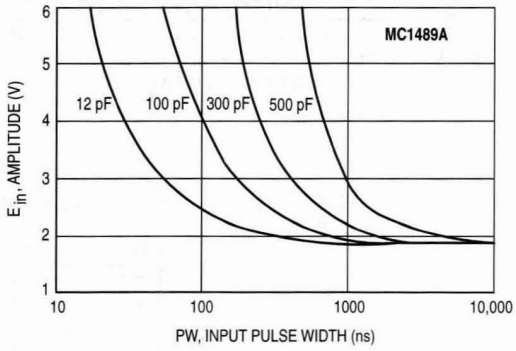


**Figure 10. Typical Translator Application – MOS to DTL or TTL**

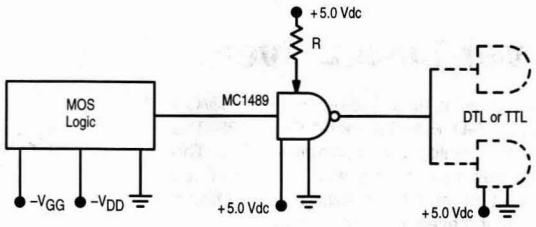
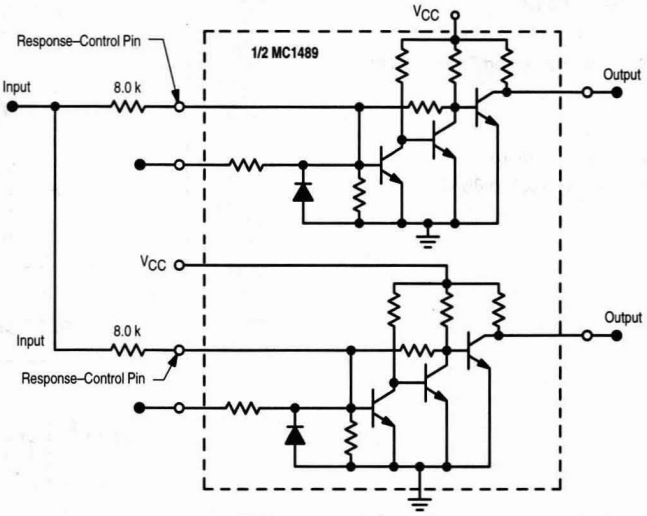



**Figure 11. Typical Paralleling of Two MC1489, A Receivers to Meet EIA–232D**




7

MOTOROLA

# MC14C88B

# Quad Low Power Line Driver

The MC14C88B is a low power monolithic quad line driver, using BiMOS technology, which conforms to EIA–232–D, EIA–562, and CCITT V.28. The inputs feature TTL and CMOS compatibility with minimal loading. The outputs feature internally controlled slew rate limiting, eliminating the need for external capacitors. Power off output impedance exceeds 300 Ω, and current limiting protects the outputs in the event of short circuits.

Power supply current is less than 160 μA over the supply voltage range of ±4.5 to ±15 V. EIA–232–D performance is guaranteed with a minimum supply voltage of ±6.5 V.

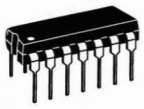
The MC14C88B is pin compatible with the MC1488, SN75188, SN75C188, DS1488, and DS14C88. This device is available in 14 pin plastic DIP, and surface mount packaging.

**Features:**

- BiMOS Technology for Low Power Operation ( < 5.0 mW)
- Meets Requirements of EIA–232–D, EIA–562, and CCITT V.28
- Quiescent Current Less Than 160 μA
- TTL/CMOS Compatible Inputs
- Minimum 300 Ω Output Impedance when Powered Off
- Supply Voltage Range: ±4.5 to ±15 V
- Pin Equivalent to MC1488
- Current Limited Output: 10 mA Minimum
- Operating Ambient Temperature: –40° to 85°C

**QUAD LOW POWER LINE DRIVER**

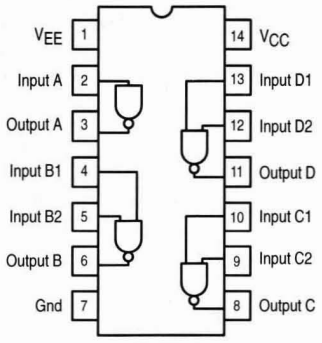
**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 646

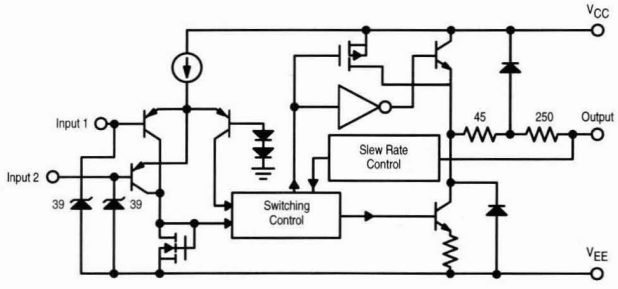
**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**PIN CONNECTIONS**




(Top View)

**Representative Block Diagram**
(Each Driver)




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC14C88BP | $T_A$ = – 40° to +85°C | Plastic DIP |
| MC14C88BD | | SO–14 |

**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage<br>$V_{CC(max)}$<br>$V_{EE(min)}$<br>$(V_{CC} - V_{EE})_{max}$ | <br>$V_{CC}$<br>$V_{EE}$<br>$V_{CC} - V_{EE}$ | <br>+17<br>–17<br>34 | Vdc |
| Input Voltage (All Inputs) | $V_{in}$ | $V_{EE}$–0.3, $V_{EE}$+39 | Vdc |
| Applied Output Voltage, when $V_{CC}$=$V_{EE}$ ≠ 0 V<br>Applied Output Voltage, when $V_{CC}$=$V_{EE}$ = 0 V | $V_X$ | $V_{EE}$–6.0 V, $V_{CC}$+6.0 V<br>±15 | Vdc |
| Output Current | $I_O$ | Self Limiting | mA |
| Operating Junction Temperature | $T_J$ | – 65, + 150 | °C |

Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides for actual device operation.

**RECOMMENDED OPERATING CONDITIONS**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$<br>$V_{EE}$ | +4.5<br>–15 | –<br>– | +15<br>–4.5 | Vdc |
| Input Voltage (All Inputs) | $V_{in}$ | 0 | – | $V_{CC}$ | Vdc |
| Applied Output Voltage ($V_{CC}$=$V_{EE}$=0 V) | $V_O$ | –2.0 | 0 | +2.0 | Vdc |
| Output DC Load | $R_L$ | 3.0 | – | 7.0 | kΩ |
| Operating Ambient Temperature Range | $T_A$ | –40 | – | +85 | °C |

All limits are not necessarily functional concurrently.

**ELECTRICAL CHARACTERISTICS** (–40°C ≤ $T_A$ ≤ +85°C, unless otherwise noted.)*

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current ($I_{out}$ = 0, see Figure 2)<br>$I_{CC}$ @ 4.75 V ≤ $V_{CC}$, –$V_{EE}$ ≤ 15 V<br>Outputs High<br>Outputs Low<br>$I_{EE}$<br>Outputs High<br>Outputs Low | <br><br>$I_{CC(OH)}$<br>$I_{CC(OL)}$<br><br>$I_{EE(OH)}$<br>$I_{EE(OL)}$ | <br><br>–<br>–<br><br>–160<br>–160 | <br><br>–<br>–<br><br>–<br>– | <br><br>160<br>160<br><br>–<br>– | µA |
| Output Voltage – High, $V_{in}$ ≤ 0.8 V ($R_L$ = 3.0 kΩ, see Figure 3)<br>$V_{CC}$ = +4.75 V, $V_{EE}$ = –4.75 V<br>$V_{CC}$ = +5.0 V, $V_{EE}$ = –5.0 V<br>$V_{CC}$ = +6.5 V, $V_{EE}$ = –6.5 V<br>$V_{CC}$ = +12 V, $V_{EE}$ = –12 V<br>$V_{CC}$ = +13.2 V, $V_{EE}$ = –13.2 V ($R_L$ = ∞)<br>Output Voltage – Low, $V_{in}$ ≥ 2.0 V<br>$V_{CC}$ = +4.75 V, $V_{EE}$ = –4.75 V<br>$V_{CC}$ = +5.0 V, $V_{EE}$ = –5.0 V<br>$V_{CC}$ = +6.5 V, $V_{EE}$ = –6.5 V<br>$V_{CC}$ = +12 V, $V_{EE}$ = –12 V<br>$V_{CC}$ = +13.2 V, $V_{EE}$ = –13.2 V ($R_L$ = ∞) | $V_{OH}$<br><br><br><br><br><br>$V_{OL}$<br><br><br><br><br> | <br>3.7<br>4.0<br>5.0<br>10<br>–<br><br>–<br>–<br>–<br>–<br>–13.2 | <br>3.8<br>4.3<br>6.1<br>10.5<br>13.2<br><br>–3.8<br>–4.2<br>–6.0<br>–10.5<br>–13.2 | <br>–<br>–<br>–<br>–<br>13.2<br><br>–3.7<br>–4.0<br>–5.0<br>–10<br>– | Vdc |
| Output Short Circuit Current** (see Figure 4) ($V_{CC}$ = $\|V_{EE}\|$ = 15 V)<br>Normally High Output, shorted to ground<br>Normally Low Output, shorted to ground | $I_{OS}$ | <br>–35<br>+10 | <br>–<br>– | <br>–10<br>+35 | mA |
| Output Source Resistance<br>($V_{CC}$ = $V_{EE}$ = 0 V, –2.0 V ≤ $V_{out}$ ≤ +2.0 V) | $R_O$ | 300 | – | – | Ω |
| Input Voltage<br>Low Level<br>High Level | <br>$V_{IL}$<br>$V_{IH}$ | <br>0<br>2.0 | <br>–<br>– | <br>0.8<br>$V_{CC}$ | Vdc |

* Typicals reflect performance @ $T_A$ = 25°C
** Only one output shorted at a time, for not more than 1 second.

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**ELECTRICAL CHARACTERISTICS (continued)** ($-40°C \leq T_A \leq +85°C$, unless otherwise noted.)*

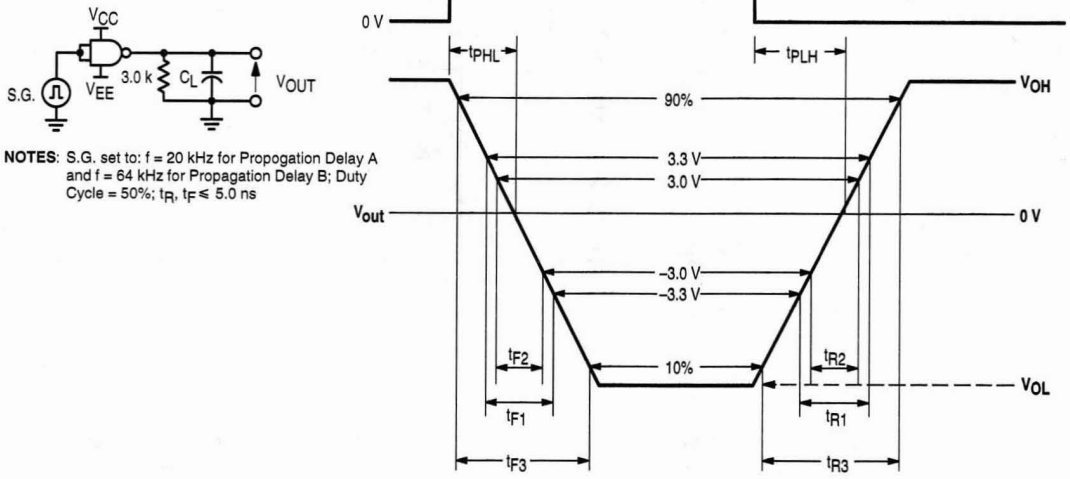
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Current | $I_{in}$ | | | | µA |
| $V_{in}$ = 0 V, $V_{CC}$ = $\|V_{EE}\|$ = 4.75 V | | –10 | –0.1 | 0 | |
| $V_{in}$ = 0 V, $V_{CC}$ = $\|V_{EE}\|$ = 15 V | | –10 | –0.1 | 0 | |
| $V_{in}$ = 4.5 V, $V_{CC}$ = $\|V_{EE}\|$ = 4.75 V | | 0 | +0.1 | +10 | |
| $V_{in}$ = 4.5 V, $V_{CC}$ = $\|V_{EE}\|$ = 15 V | | 0 | +0.1 | +10 | |

**TIMING CHARACTERISTICS** ($-40°C \leq T_A \leq +85°C$, unless otherwise noted.)*

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Rise Time | | | | | µs |
| $V_{CC}$ = 4.75 V, $V_{EE}$ = –4.75 V | | | | | |
| –3.3 V ≤ $V_O$ ≤ 3.3 V | $t_{R1}$ | | | | |
| $C_L$ = 15 pF | | 0.22 | 0.66 | 2.1 | |
| $C_L$ = 1000 pF | | 0.22 | 1.52 | 2.1 | |
| –3.0 V ≤ $V_O$ ≤ 3.0 V | $t_{R2}$ | | | | |
| $C_L$ = 15 pF | | 0.20 | 0.51 | 1.5 | |
| $C_L$ = 1000 pF | | 0.20 | 1.16 | 1.5 | |
| $V_{CC}$ = 12.0 V, $V_{EE}$ = –12.0 V | | | | | |
| –3.0 V ≤ $V_O$ ≤ 3.0 V | | | | | |
| $C_L$ = 15 pF | | 0.20 | 0.62 | 1.5 | |
| $C_L$ = 2500 pF | | 0.20 | 0.82 | 1.5 | |
| 10% ≤ $V_O$ ≤ 90% | $t_{R3}$ | | | | |
| $C_L$ = 15 pF | | 0.53 | 1.41 | 3.2 | |
| Output Fall Time | | | | | µs |
| $V_{CC}$ = 4.75 V, $V_{EE}$ = –4.75 V | | | | | |
| 3.3 V ≤ $V_O$ ≤ –3.3 V | $t_{F1}$ | | | | |
| $C_L$ = 15 pF | | 0.22 | 0.93 | 2.1 | |
| $C_L$ = 1000 pF | | 0.22 | 1.28 | 2.1 | |
| 3.0 V ≤ $V_O$ ≤ –3.0 V | $t_{F2}$ | | | | |
| $C_L$ = 15 pF | | 0.20 | 0.72 | 1.5 | |
| $C_L$ = 1000 pF | | 0.20 | 1.01 | 1.5 | |
| $V_{CC}$ = 12.0 V, $V_{EE}$ = –12.0 V | | | | | |
| 3.0 V ≤ $V_O$ ≤ –3.0 V | | | | | |
| $C_L$ = 15 pF | | 0.20 | 0.70 | 1.5 | |
| $C_L$ = 2500 pF | | 0.20 | 0.94 | 1.5 | |
| 90% ≤ $V_O$ ≤ 10% | $t_{F3}$ | | | | |
| $C_L$ = 15 pF | | 0.53 | 1.71 | 3.2 | |
| Output Slew Rate, 3.0 kΩ < $R_L$ < 7.0 kΩ, 15 pF < $C_L$ < 2500 pF | $S_R$ | 4.0 | – | 30 | V/µs |
| Propagation Delay A ($C_L$ = 15 pF, see Figure 1) | | | | | µs |
| $V_{CC}$ = 12.0 V, $V_{EE}$ = –12.0 V | | | | | |
| Input to Output – Low to High | $t_{PLH}$ | – | 0.9 | 3.0 | |
| Input to Output – High to Low | $t_{PHL}$ | – | 2.3 | 3.5 | |
| Propagation Delay B ($C_L$ = 15 pF, see Figure 1) | | | | | |
| $V_{CC}$ = 4.75 V, $V_{EE}$ = –4.75 V | | | | | |
| Input to Output – Low to High | $t_{PLH}$ | – | 0.4 | 2.0 | |
| Input to Output – High to Low | $t_{PHL}$ | – | 1.5 | 2.5 | |

* Typicals reflect performance @ $T_A = 25°C$

**Figure 1. Timing Diagram**




**NOTES:** S.G. set to: f = 20 kHz for Propogation Delay A and f = 64 kHz for Propagation Delay B; Duty Cycle = 50%; $t_R$, $t_F \leq$ 5.0 ns

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## STANDARDS COMPLIANCE

The MC14C88 is designed to comply with EIA–232–D (formerly RS–232), the newer EIA–562 (which is a higher speed version of the EIA–232), and CCITT's V.28. EIA–562 was written around modern integrated circuit technology, whereas EIA–232 retains many of the specs written around the electro–mechanical circuitry in use at the time of its creation. Yet the user will find enough similarities to allow a certain amount of compatibility among equipment built to the two standards. Following is a summary of the key specifications relating to the systems and the drivers.

| Parameter | EIA–232–D | EIA–562 |
|---|---|---|
| Maximum Data Rate | 20 kbaud | 38.4 kbaud Asynchronous<br>64 kbaud Synchronous |
| Maximum Cable Length | 50 feet | Based on cable capacitance/data rate |
| Maximum Slew Rate | $\leq$ 30 V/μs anywhere on the waveform | $\leq$ 30 V/μs anywhere on the waveform<br>$\geq$ 4.0 V/μs between +3.0 and –3.0 V |
| Transition Region | –3.0 to +3.0 V | –3.3 to +3.3 V |
| Transition Time | For UI $\geq$ 25 ms, $t_R \leq$ 1.0 ms<br>For 25 ms > UI > 125 μs, $t_R \leq$ 4% UI<br>For UI < 125 μs, $t_R \leq$ 5.0 μs | For UI $\geq$ 50 μs, 220 ns < $t_R \leq$ 3.1 μs<br>For UI < 50 μs, 220 ns < $t_R \leq$ 2.1 μs<br>(within the transition region) |
| MARK (one, off) | More negative than –3.0 V | More negative than –3.3 V |
| Space (zero, on) | More positive than +3.0 V | More positive than +3.3 V |
| Short Circuit Proof ? | Yes, to any system voltage | Yes, to ground |
| Short Circuit Current | $\leq$ 500 mA to any system voltage | $\leq$ 60 mA to ground |
| Open Circuit Voltage | $\lvert V_{OC}\rvert \leq$ 25 V | $\lvert V_{OC}\rvert <$ 13.2 V |
| Loaded Output Voltage | 5.0 V $\leq \lvert V_O\rvert \leq$ 15 V for loads between 3.0 kΩ and 7.0 kΩ | $\lvert V_O\rvert \geq$ 3.7 V for a load of 3.0 kΩ |
| Power Off Input Source Impedance | $\geq$ 300 Ω for $\lvert V_O\rvert \leq$ 2.0 V | $\geq$ 300 Ω for $\lvert V_O\rvert \leq$ 2.0 V |

**NOTE:** UI = Unit Interval, or bit time.
V.28 standard has the same specifications as EIA–232, with the exception of transition time which is listed as "less than 1.0 ms, or 3% of the UI, whichever is less".

**Figure 2. Typical Supply Current versus Supply Voltage**

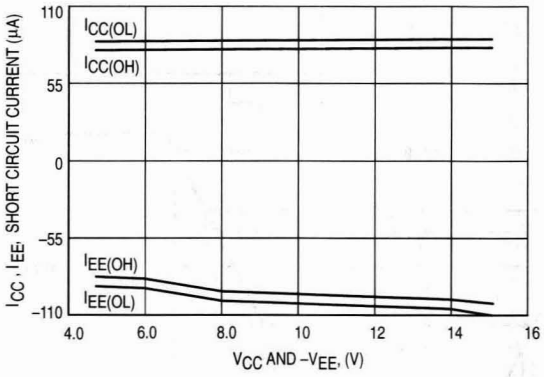



**Figure 3. Typical Output Voltage versus Supply Voltage**

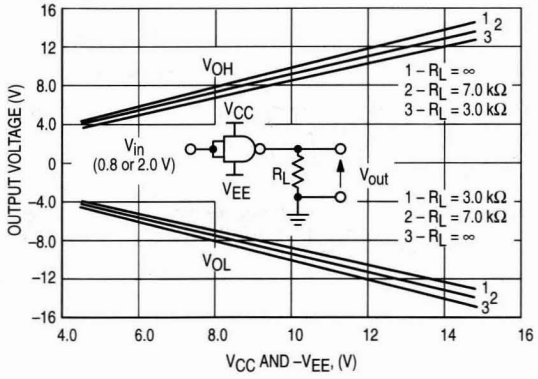



**Figure 4. Typical Short Circuit Current versus Supply Voltage**

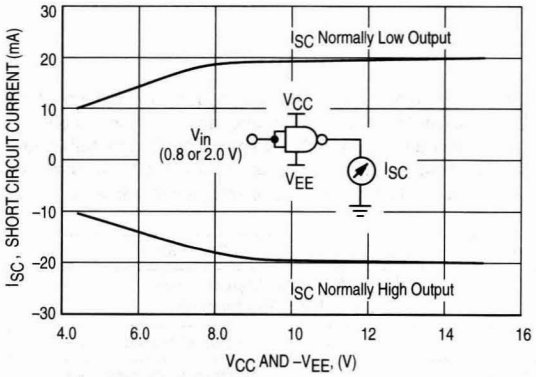
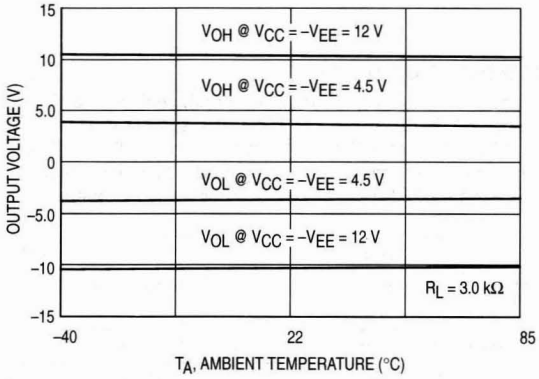



**Figure 5. Typical Output Voltage versus Temperature**



## APPLICATIONS INFORMATION

### Description

The MC14C88 was designed to be a direct replacement for the MC1488 in that it meets all EIA–232 specifications. However, use is extended as the MC14C88 also meets the faster EIA–562 and CCITT V.28 specifications. Slew rate limited outputs conform to the mentioned specifications and eliminate the need for external output capacitors. Low power consumption is made possible by BiMOS technology. Power supply current is limited to less than 160 μA, plus load currents over the supply voltage range of ±4.5 V to ±15 V (see Figure 2).

### Outputs

The output low or high voltage depends on the state of the inputs, the load current, and the supply voltage (see Table 1 and Figure 3). The graphs apply to each driver regardless of how many other drivers within the package are supplying load current.

**Table 1. Function Tables**

Driver 1

| Input A | Output A |
|---|---|
| H | L |
| L | H |

Drivers 2 through 4

| Input *1 | Input *2 | Output* |
|---|---|---|
| H | H | L |
| L | X | H |
| X | L | H |

H = High level, L = Low level, X = Don't care.

### Driver Inputs

The driver inputs determine the state of the outputs in accordance with Table 1. The nominal threshold voltage for the inputs is 1.4 Vdc, and for proper operation, the input voltages should be restricted to the range Gnd to $V_{CC}$. Should the input voltage drop below $V_{EE}$ by more than 0.3 V or rise above $V_{EE}$ by more than 39 V, excessive currents will flow at the input pin. Open input pins are equivalent to logic high, but good design practices dictate that inputs should never be left open.

### Operating Temperature Range

The ambient operating temperature range is listed at –40° to +85°C and meets EIA–232–D, EIA–562 and CCITT V.28 specifications over this temperature range. The maximum ambient temperature is listed as +85°C. However, a lower ambient may be required depending on system use, i.e. specifically how many drivers within a package are used, and at what current levels they are operating. The maximum power which may be dissipated within the package is determined by:

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{R_{\theta\ JA}}$$

where: $R_{\theta JA}$ = the package thermal resistance (typically, 100°C/W for the DIP package, 125°C/W for the SOIC package);
$T_{Jmax}$ = the maximum operating junction temperature (150°C); and
$T_A$ = the ambient temperature.

$P_D = \{ [ (V_{CC} - V_{OH}) \times |I_{OH}| ]$ or $[ (V_{OL} - V_{EE}) \times |I_{OL}| ] \}$ each driver $+ (V_{CC} \times I_{CC}) + (V_{EE} \times I_{EE})$

where: $V_{CC}$ and $V_{EE}$ are the positive and negative supply voltages;
$V_{OH}$ and $V_{OL}$ are measured or estimated from Figure 3;
$I_{CC}$ and $I_{EE}$ are the quiescent supply currents measured or estimated from Figure 2.

As indicated, the first term (in brackets) must be calculated and summed for each of the four drivers, while the last terms are common to the entire package.

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MOTOROLA

# MC14C89B, AB

# Quad Low Power Line Receivers

The MC14C89B and MC14C89AB are low monolithic quad line receivers using bipolar technology, which conform to the EIA–232–E, EIA–562 and CCITT V.28 Recommendations. The outputs feature LSTTL and CMOS compatibility for easy interface to +5.0 V digital systems. Internal time–domain filtering eliminates the need for external filter capacitors in most cases.

The MC14C89B has an input hysteresis of 0.35 V, while the MC14C89AB hysteresis is 0.95 V. The response control pins allow adjustment of the threshold level if desired. Additionally, an external capacitor may be added for additional noise filtering.

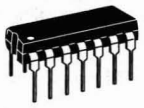
The MC14C89B and MC14C89AB are available in both a 14 pin dual–in–line plastic DIP and SOIC package.

**Features:**

- Low Power Consumption
- Meets EIA–232–E, EIA–562, and CCITT V.28 Recommendations
- TTL/CMOS Compatible Outputs
- Standard Power Supply: + 5.0 V ±10%
- Pin Equivalent to MC1489, MC1489A, TI's SN75C189/A, SN75189/A and National Semiconductor's DS14C89/A
- External Filtering Not Required in Most Cases
- Threshold Level Externally Adjustable
- Hysteresis: 0.35 V for MC14C89B, 0.95 V for MC14C89AB
- Available in Plastic DIP, and Surface Mount Packaging
- Operating Ambient Temperature: –40° to +85°C

**QUAD LOW POWER LINE RECEIVERS**

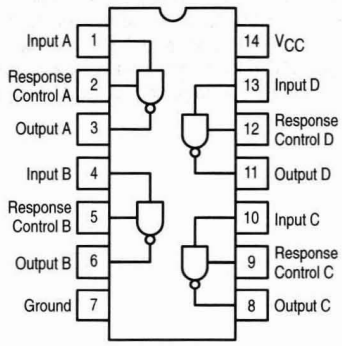
**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 646

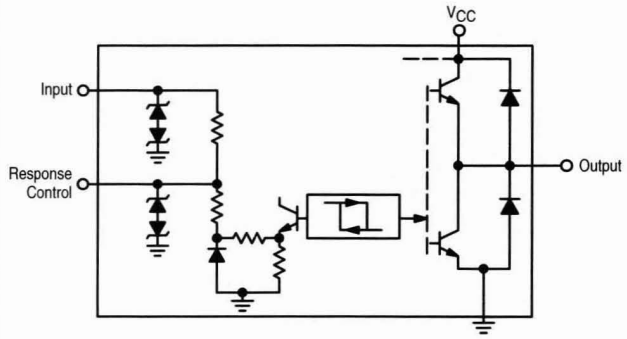
**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**PIN CONNECTIONS**




(Top View)

**Representative Block Diagram (Each Receiver)**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC14C89BP | $T_A$ = – 40° to +85°C | Plastic DIP |
| MC14C89ABP | | Plastic DIP |
| MC14C89ABD | | SO–14 |

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage<br>$V_{CC(max)}$<br>$V_{CC(min)}$ | $V_{CC}$ | <br>+7.0<br>−0.5 | Vdc |
| Input Voltage | $V_{in}$ | ±30 | Vdc |
| Output Load Current | $I_O$ | Self–Limiting | – |
| Junction Temperature | $T_J$ | −65, +150 | °C |

Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides for actual device operation.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.5 | 5.0 | 5.5 | Vdc |
| Input Voltage | $V_{in}$ | −25 | – | 25 | Vdc |
| Output Current Capability | $I_O$ | −7.5 | – | 6.0 | mA |
| Operating Ambient Temperature | $T_A$ | −40 | – | 85 | °C |

All limits are not necessarily functional concurrently.

## ELECTRICAL CHARACTERISTICS (−40°C ≤ $T_A$ ≤ +85°C, unless otherwise noted.)*

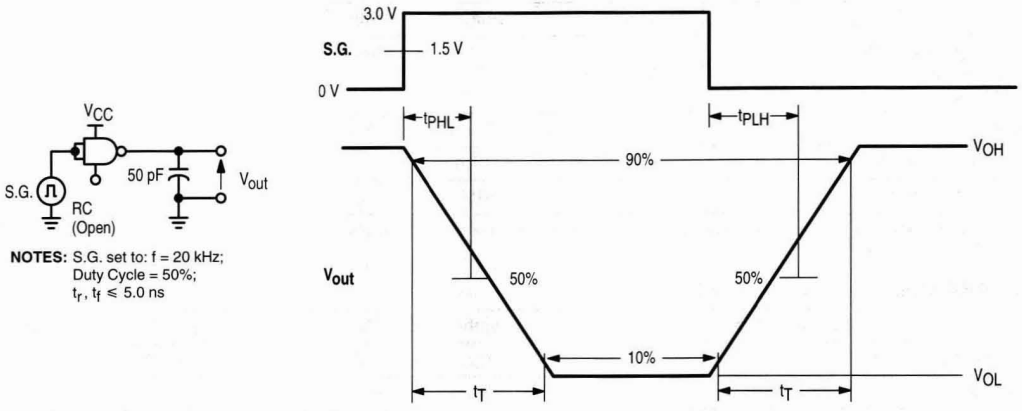
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current ($I_{out}$ = 0)<br>$I_{CC}$ @ +4.5 V ≤ $V_{CC}$ ≤ +5.5 V | $I_{CC}$ | – | 330 | 700 | µA |
| Output Voltage – High, $V_{in}$ ≤ 0.4 V (See Figures 2 and 3) | $V_{OH}$ | | | | Vdc |
| $I_{out}$ = −20 µA $V_{CC}$ = 4.5 V | | 3.5 | 3.8 | – | |
| $V_{CC}$ = 5.5 V | | 3.5 | 4.8 | – | |
| $I_{out}$ = −3.2 mA $V_{CC}$ = 4.5 V | | 2.5 | 3.7 | – | |
| $V_{CC}$ = 5.5 V | | 2.5 | 4.7 | – | |
| Output Voltage – Low, $V_{in}$ ≥ 2.4 V | $V_{OL}$ | | | | |
| $I_{out}$ = 3.2 mA $V_{CC}$ = 4.5 V | | – | 0.1 | 0.4 | |
| $V_{CC}$ = 5.5 V | | – | 0.1 | 0.4 | |
| Output Short Circuit Current** ($V_{CC}$ = 5.5 V, see Figure 4) | $I_{OS}$ | | | | mA |
| Normally High Output shorted to ground | | −35 | −13.9 | – | |
| Normally Low Output shorted to $V_{CC}$ | | – | +10.3 | 35 | |
| Input Threshold Voltage ($V_{CC}$ = 5.0 V) | | | | | |
| (MC14C89AB, see Figure 5) Low Level | $V_{IL}$ | 0.75 | 0.95 | 1.25 | Vdc |
| High Level | $V_{IH}$ | 1.6 | 1.90 | 2.25 | |
| (MC14C89B, see Figure 6) | $V_{IL}$ | 0.75 | 0.95 | 1.25 | |
| Low Level | $V_{IH}$ | 1.0 | 1.3 | 1.5 | |
| High Level | | | | | |
| Input Impedance (+4.5 V < $V_{CC}$ < +5.5 V −25 V < $V_{in}$ < +25 V) | | 3.0 | 5.5 | 7.0 | kΩ |

* Typicals reflect performance @ $T_A$ = 25°C
**Only one output shorted at a time, for not more than 1.0 seconds.

## TIMING CHARACTERISTICS ($T_A$ = +25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Transition Time (10% to 90%)<br>4.5 V ≤ $V_{CC}$ ≤ 5.5 V | $t_T$ | – | 0.08 | 0.30 | µs |
| Propagation Delay Time<br>4.5 V ≤ $V_{CC}$ ≤ 5.5 V | | | | | |
| Output Low–to–High | $t_{PLH}$ | – | 3.35 | 6.0 | µs |
| Output High–to–Low | $t_{PHL}$ | – | 2.55 | 6.0 | |
| Input Noise Rejection (see Figure 9) | | 1.0 | 1.5 | – | µs |

**Figure 1. Timing Diagram**




## STANDARDS COMPLIANCE

The MC14C89B and MC14C89AB are designed to comply with EIA–232–E (formerly RS–232), the newer EIA–562 (which is a higher speed version of the EIA–232), and CCITT V.28 Recommendations. EIA–562 was written around modern integrated circuit technology, whereas EIA–232 retains many of the specifications written around the electro–mechanical circuitry in use at the time of its creation. Yet the user will find enough similarities to allow a certain amount of compatibility among equipment built to the two standards. Following is a summary of the key specifications relating to the systems and the receivers.

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| Parameter | EIA–232–E | EIA–562 |
|---|---|---|
| Max Data Rate | 20 kBaud | 38.4 kBaud Asynchronous<br>64 kBaud Synchronous |
| Max Cable Length | 50 feet | Based on cable capacitance/data rate |
| Transition Region | –3.0 V to +3.0 V | –3.0 V to +3.0 V |
| MARK (one, off) | More negative than –3.0 V | More negative than –3.3 V |
| SPACE (zero, on) | More positive than +3.0 V | More positive than +3.3 V |
| Fail Safe | Output = Binary 1 | Output = Binary 1 |
| Open Circuit Input Voltage | < \|2.0\| V | Not Specified |
| Slew Rate (at the driver) | ≤30 V/μs anywhere on the waveform | ≤30 V/μs anywhere on the waveform,<br>≥4.0 V/μs between +3.0 V and –3.0 V |
| Loaded Output Voltage (at the driver) | 5.0 V ≤ \|$V_O$\| ≤ 15 V for loads between 3.0 kΩ and 7.0 kΩ | \|$V_O$\| ≥ 3.7 V for a load of 3.0 kΩ |

**Figure 2. Typical Output versus Supply Voltage**

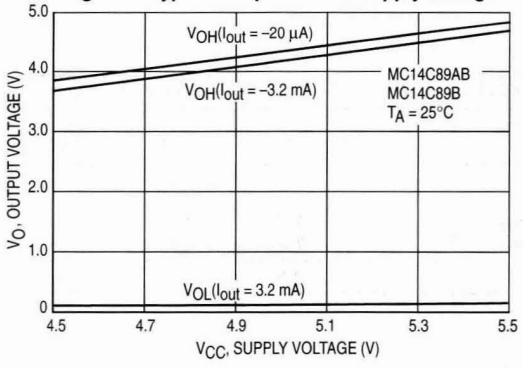



**Figure 3. Typical Output Voltage versus Temperature**

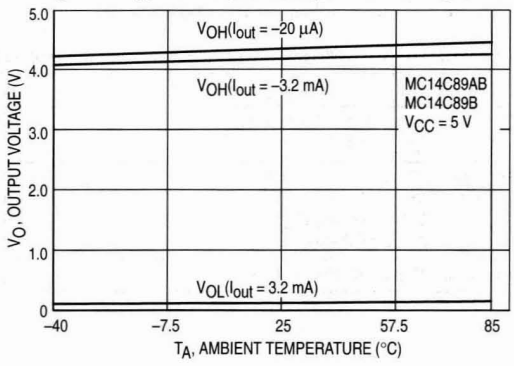


**Figure 4. Typical Short Circuit Current versus Temperature**

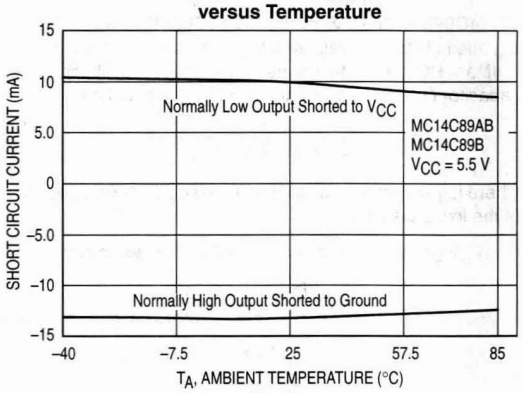



**Figure 5. Typical Threshold Voltage versus Temperature**

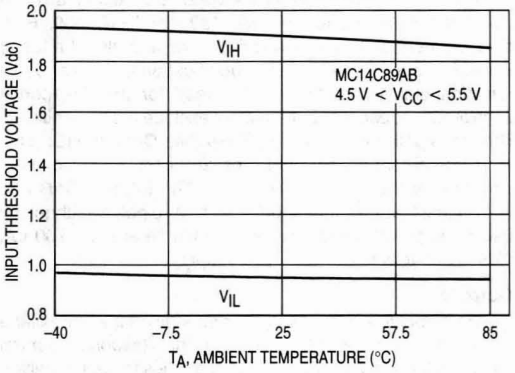



**Figure 6. Typical Threshold Voltage versus Temperature**

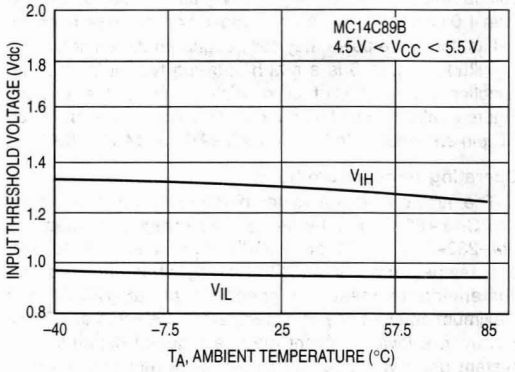



**Figure 7. Typical Effect of Response Control Pin Bias**

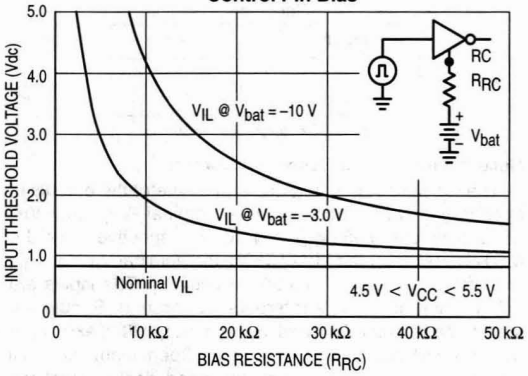
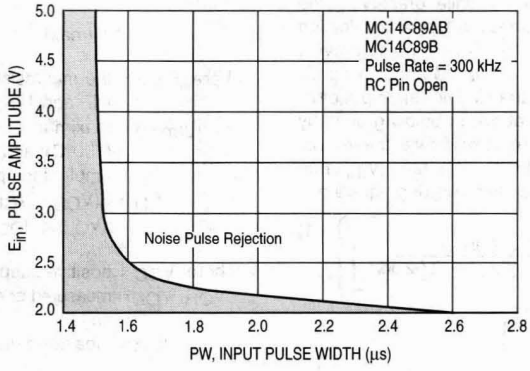



**Figure 8. Typical Noise Pulse Rejection**

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## APPLICATIONS INFORMATION

### Description

The MC14C89AB and MC14C89B are designed to be direct replacements for the MC1489A and MC1489. Both devices meet all EIA–232 specifications and also the faster EIA–562 and CCITT V.28 specifications. Noise pulse rejection circuitry eliminates the need for most response control filter capacitors but does not exclude the possibility as filtering is still possible at the Response Control (RC) pins. Also, the Response Control pins allow for a user defined selection of the threshold voltages. The MC14C89AB and MC14C89B are manufactured with a bipolar technology using low power techniques and consume at most 700 μA, plus load currents with a +5.0 V supply.

### Outputs

The output low or high voltage depends on the state of the inputs, the load current, the bias of the Response Control pins, and the supply voltage. Table 1 applies to each receiver, regardless of how many other receivers within the package are supplying load current.

**Table 1. Function Table**

Receivers

| Input* | Output* |
|---|---|
| H | L |
| L | H |

*The asterisk denotes A, B, C, or D.

7

### Receiver Inputs and Response Control

The receiver inputs determine the state of the outputs in accordance with Table 1. The nominal $V_{IL}$ and $V_{IH}$ thresholds are 0.95 V and 1.90 V respectively for the MC14C89AB. For the MC14C89B, the nominal $V_{IL}$ and $V_{IH}$ thresholds are 0.95 and 1.30, respectively. The inputs are able to withstand ±30 V referenced to ground. Should the input voltage exceed ground by more than ±30 V, excessive currents will flow at the input pin. Open input pins will generate a logic high output, but good design practices dictate that inputs should never be left open.

The Response Control (RC) pins are coupled to the inputs through a resistor string. The RC pins provide for adjustment of the threshold voltages of the IC while preserving the amount of hysteresis. Figure 10 shows a typical application to adjust the threshold voltages. The RC pins also provide access to an internal resistor string which permits low pass filtering of the input signal within the IC. Like the input pins, the RC pins should not be taken above or below ground by more than ±30 V or excessive currents will flow at these pins. The dependence of the low level threshold voltage ($V_{IL}$) upon $R_{RC}$ and $V_{bat}$ can be described by the following equation:

$$V_{IL} \simeq \left\{ V_{0.09} - V_{bat} \left[ \frac{505\ \Omega}{R_{RC}\ (1.6)\ +\ 2.02\ k\Omega} \right] \right\} \left[ \frac{5.32\ k\Omega\ +\ \frac{6.67 \times 10^6\ \Omega 2}{R_{RC}}}{505\ \Omega} \right] \quad (1)$$

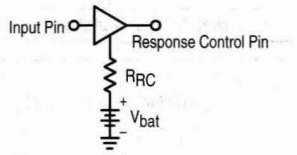
$V_{IH}$ can be found by calculating for $V_{IL}$ using equation (1) then adding the hysteresis for each device (0.35 for the MC14C89B or 0.95 V for the MC14C89AB). Figure 7 plots equation (1) for two values of $V_{bat}$ and a range of $R_{RC}$.

If an RC pin is to be used for low pass filtering, the capacitor chosen can be calculated by the equation,

$$C_{RC} \simeq \frac{1}{2.02\ k\Omega\ 2\pi\ f_{-3dB}} \quad (2)$$

where $f_{-3\,dB}$ represents the desired –3 dB role–off frequency of the low pass filter.

**Figure 9. Application to Adjust Thresholds**




Another feature of the MC14C89AB and MC14C89B is input noise rejection. The inputs have the ability to ignore pulses which exceed the $V_{IH}$ and $V_{IL}$ thresholds but are less than 1.0 μs in duration. As the duration of the pulse exceeds 1.0 μs, the noise pulse may still be ignored depending on its amplitude. Figure 8 is a graph showing typical input noise rejection as a function of pulse amplitude and pulse duration. Figure 8 reflects data taken for an input with an unconnected RC pin and applied to the MC14C89AB and MC14C89B.

### Operating Temperature Range

The ambient operating temperature range is listed as –40°C to +85°C, and the devices are designed to meet the EIA–232–E, EIA–562 and CCITT V.28 specifications over this temperature range. The timing characteristics are guaranteed to meet the specifications at +25°C. The maximum ambient operating temperature is listed as +85°C. However, a lower ambient may be required depending on system use (i.e., specifically how many receivers within a package are used), and at what current levels they are operating. The maximum power which may be dissipated within the package is determined by:

$$P_{D(max)} = \frac{T_{J(max)} - T_A}{R_{\theta JA}}$$

where: $R_{\theta JA}$ = thermal resistance (typ., 100°C/W for the DIP and 125°C/W for the SOIC packages);
$T_{J(max)}$ = maximum operating junction temperature (150°C); and
$T_A$ = ambient temperature.
$P_D = \{[(V_{CC} - V_{OH}) \times |I_{OH}|]$ or $[(V_{OL}) \times |I_{OL}|]\}_{\text{each receiver}} + (V_{CC} \times I_{CC})$

where: $V_{CC}$ = positive supply voltage;
$V_{OH}$, $V_{OL}$ = measured or estimated from Figure 2 and 3;
$I_{CC}$ = measured quiescent supply current.

As indicated, the first term (in brackets) must be calculated and summed for each of the four receivers, while the last term is common to the entire package.

MOTOROLA

# MC26S10

# Quad Open-Collector Bus Transceiver

**QUAD OPEN–COLLECTOR BUS TRANSCEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

This quad transceiver is designed to mate Schottky TTL or NMOS logic to a low impedance bus. The $\overline{\text{Enable}}$ and Driver inputs are PNP buffered to ensure low input loading. The Driver (Bus) output is open–collector and can sink up to 100 mA at 0.8 V, thus the bus can drive impedances as low as 100 Ω. The receiver output is active pull–up and can drive ten Schottky TTL loads.

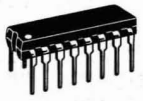
An active–low $\overline{\text{Enable}}$ controls all four drivers allowing the outputs of different device drivers to be connected together for party–line operation. The line can be terminated at both ends and still give considerable noise margin at the receiver. Typical receiver threshold is 2.0 V.

Advanced Schottky processing is utilized to assure fast propagation delay times. Two ground pins are provided to improve ground current handling and allow close decoupling between $V_{CC}$ and ground at the package. Both ground pins should be tied to the ground bus external to the package.

- Driver Can Sink 100 mA at 0.8 V (Maximum)
- PNP Inputs for Low–Logic Loading
- Typical Driver Delay = 10 ns
- Typical Receiver Delay = 10 ns
- Schottky Processing for High Speed
- Inverting Driver

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

**P SUFFIX**
PLASTIC PACKAGE
CASE 648

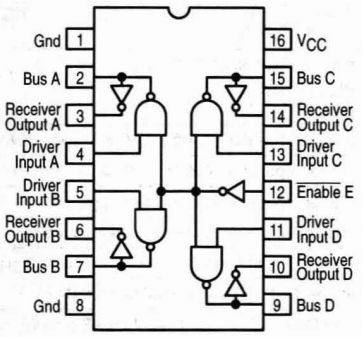


Not Recommended For New Designs

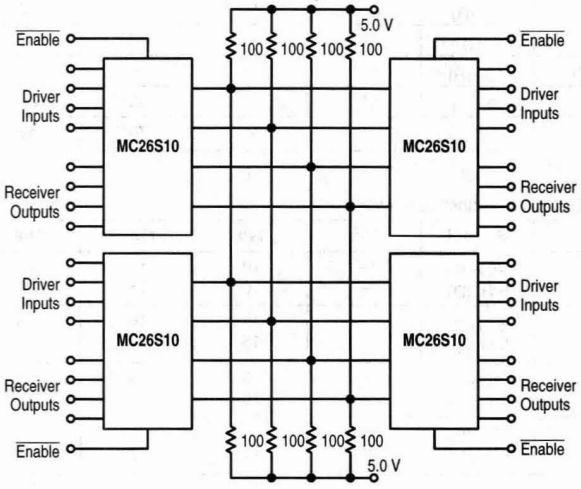
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC26S10P | $T_A$ = 0 to +70°C | Plastic DIP |
| MC26S10D | | SO–16 |

**PIN CONNECTIONS**




**Simplified Application**




**TRUTH TABLE**

| $\overline{\text{Enable}}$ | Driver Input | Bus | Receiver Output |
|---|---|---|---|
| L | L | H | L |
| L | H | L | H |
| H | X | Y | Y |

L = Low Logic State
H = High Logic State
X = Irrelevant
Y = Assumes condition controlled by other elements on the bus

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | –0.5 to +7.0 | Vdc |
| Input Voltage | $V_I$ | –0.5 to +5.5 | Vdc |
| Input Current | $I_I$ | –3.0 to +5.0 | mA |
| Output Voltage – High Impedance State | $V_{O\ (Hi-z)}$ | –0.5 to $V_{CC}$ | V |
| Output Current – Bus | $I_{O(B)}$ | 200 | mA |
| Output Current – Receiver | $I_{O(R)}$ | 30 | mA |
| Operating Ambient Temperature | $T_A$ | 0 to +70 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Junction Temperature | $T_J$ | 150 | °C |

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted $V_{CC}$ = 4.75 to 5.25 V and $T_A$ = 0 to +70°C. Typical values measured at $V_{CC}$ = 5.0 V and $T_A$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Voltage – Low Logic State (Driver and $\overline{\text{Enable}}$ Inputs) | $V_{IL}$ | – | – | 0.8 | V |
| Input voltage – High Logic State (Driver and $\overline{\text{Enable}}$ Inputs) | $V_{IH}$ | 2.0 | – | – | V |
| Input Clamp Voltage (Driver and Enable Inputs)<br>($I_{IK}$ = –18 mA) | $V_{IK}$ | – | – | –1.2 | V |
| Input Current – Low Logic State ($V_{IL}$ = 0.4 V)<br>($\overline{\text{Enable}}$ Input)<br>(Driver Inputs) | $I_{IL}$ | <br>–<br>– | <br>–<br>– | <br>–0.36<br>–0.54 | mA |
| Input Current – High Logic State ($V_{IH}$ = 2.7 V)<br>($\overline{\text{Enable}}$ Input)<br>(Driver Inputs) | $I_{IH}$ | <br>–<br>– | <br>–<br>– | <br>20<br>30 | µA |
| Input Current – Maximum Voltage ($V_{IH1}$ = 5.5 V)<br>($\overline{\text{Enable}}$ or Driver Inputs) | $I_{IH1}$ | – | – | 100 | µA |
| Driver Output Voltage – Low Logic State<br>($I_{OL}$ = 40 mA)<br>($I_{OL}$ = 70 mA)<br>($I_{OL}$ = 100 mA) | $V_{OL(D)}$ | <br>–<br>–<br>– | <br>0.33<br>0.42<br>0.51 | <br>0.5<br>0.7<br>0.8 | V |
| Driver (Bus) Leakage Current<br>($V_{OH}$ = 4.5 V)<br>($V_{OL}$ = 0.8 V) | $I_{O(D)}$ | <br>–<br>– | <br>–<br>– | <br>100<br>–50 | µA |
| Driver (Bus) Leakage Current ($V_{CC}$ = 0 V, $V_{OH}$ = 4.5 V) | $I_{O1(D)}$ | – | – | 100 | µA |
| Receiver Input High Threshold ($V_{IH(\overline{E})}$ = 2.4 V) | $V_{TH(R)}$ | 2.25 | 2.0 | – | V |
| Receiver Input Low Threshold ($V_{IH(\overline{E})}$ = 2.4 V) | $V_{TL(R)}$ | – | 2.0 | 1.75 | V |
| Receiver Output Voltage – Low Logic State ($I_{OL}$ = 20 mA) | $V_{OL(R)}$ | – | – | 0.5 | V |
| Receiver Output Voltage – High Logic State ($I_{OH}$ = –1.0 mA) | $V_{OH(R)}$ | 2.7 | 3.4 | – | V |
| Receiver Output Short–Circuit Current (Note1) | $I_{OS(R)}$ | –18 | – | –60 | mA |
| Power Supply Current – Output Low State ($V_{IL(\overline{E})}$ = 0 V) | $I_{CC}$ | – | 45 | 70 | mA |

**NOTE:** 1. One output shorted at a time. Duration not to exceed 1.0 second.

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time Driver Input to Output | $t_{PLH(D)}$<br>$t_{PHL(D)}$ | –<br>– | 10<br>10 | 15<br>15 | ns |
| Propagation Delay Time $\overline{\text{Enable}}$ Input to Output | $t_{PLH(\overline{E})}$<br>$t_{PHL(E)}$ | –<br>– | 14<br>13 | 18<br>18 | ns |
| Propagation Delay Time Bus to Receiver Output | $t_{PLH(R)}$<br>$t_{PHL(R)}$ | –<br>– | 10<br>10 | 15<br>15 | ns |
| Rise and Fall Time of Driver Output | $t_{TLH(D)}$<br>$t_{THL(D)}$ | 4.0<br>2.0 | 10<br>4.0 | –<br>– | ns |

Not Recommended for New Designs

## SWITCHING WAVEFORMS AND CIRCUITS

**Figure 1. Data Input to Bus Output (Driver)**

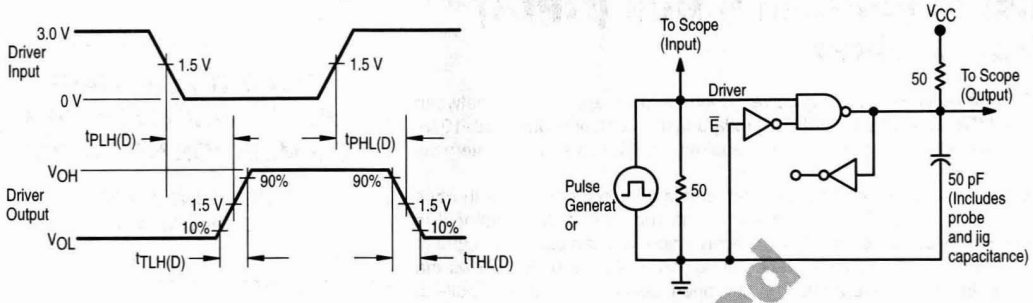
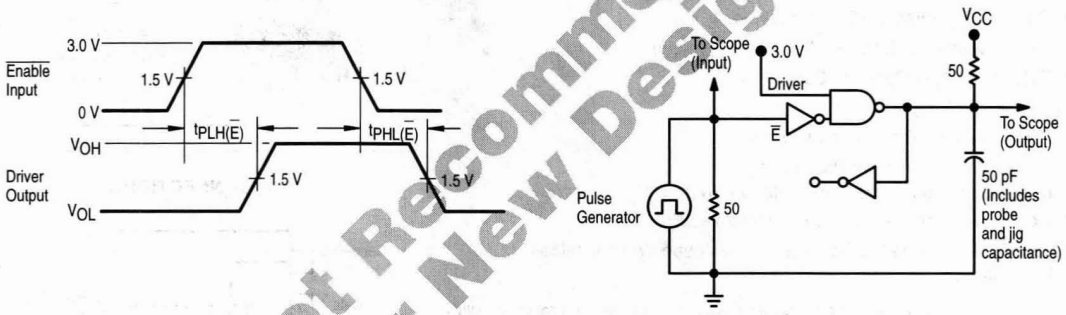
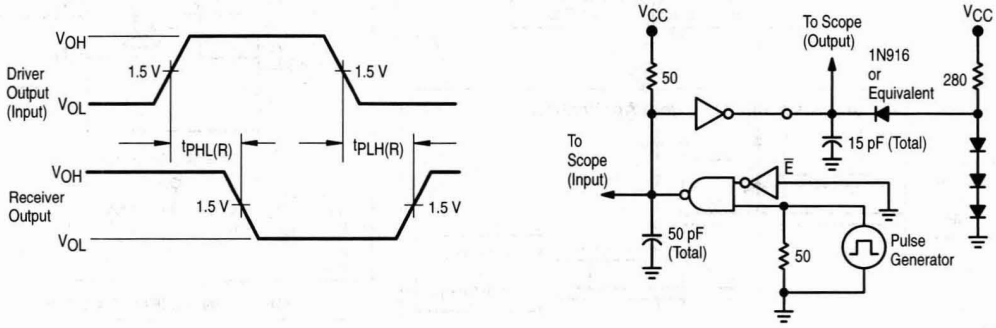



**Figure 2. Enable Input to Bus Output (Driver)**




Not Recommended For New Designs

**Figure 3. Bus Input to Receiver Output**



MOTOROLA

# MC3448A

# Quad Bidirectional Instrumentation Bus (GPIB) Transceiver

**QUAD THREE–STATE BUS TRANSCEIVER WITH TERMINATION NETWORKS**

**SEMICONDUCTOR TECHNICAL DATA**

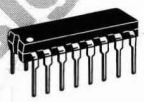
This bidirectional bus transceiver is intended as the interface between TTL or MOS logic and the IEEE Standard Instrumentation Bus (488–1978, often referred to as GPIB). The required bus termination is internally provided.

Each driver/receiver pair forms the complete interface between the bus and an instrument. Either the driver or the receiver of each channel is enabled by its corresponding Send/Receive input with the disabled output of the pair forced to a high impedance state. An additional option allows the driver outputs to be operated in an open collector* or active pull–up configuration. The receivers have input hysteresis to improve noise margin, and their input loading follows the bus standard specifications.

- Four Independent Driver/Receiver Pairs
- Three–State Outputs
- High Impedance Inputs
- Receiver Hysteresis – 600 mV (Typical)
- Fast Propagation Times – 15 to 20 ns (Typical)
- TTL Compatible Receiver Outputs
- Single 5.0 V Supply
- Open Collector Driver Output Option*
- Power Up/Power Down Protection (No Invalid Information Transmitted to Bus)
- No Bus Loading When Power Is Removed From Device
- Terminations Provided: Termination Removed When Device is Unpowered

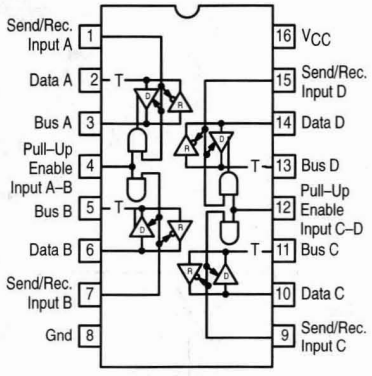
* Selection of the "Open Collector" configuration, in fact, selects an open collector device with a passive pull–up load/termination which conforms to Figure 7, IEEE 488–1978 Bus Standard.

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)



**P SUFFIX**
PLASTIC PACKAGE
CASE 648

**PIN CONNECTIONS**

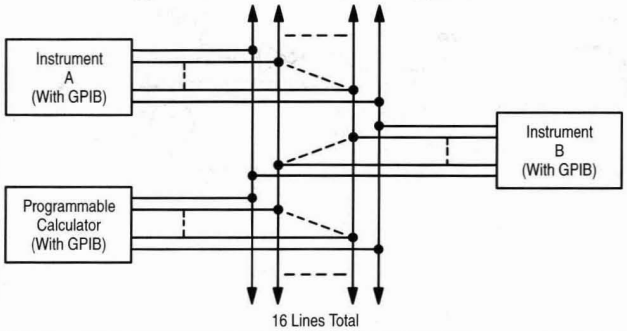



**TRUTH TABLE**

| Send/Rec. | Enable | Info. Flow | | Comments |
|---|---|---|---|---|
| 0 | X | Bus | Data | – |
| 1 | 1 | Data | Bus | Active Pull–Up |
| 1 | 0 | Data | Bus | Open Col. |

X = Don't Care

**Typical Measurement System Application**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3448AP | $T_A$ = 0 to +70°C | Plastic DIP |
| MC3448AD | | SO–16 |

Not Recommended for New Design

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 | Vdc |
| Input Voltage | $V_I$ | 5.5 | Vdc |
| Driver Output Current | $I_{O(D)}$ | 150 | mA |
| Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, 4.75 V ≤ $V_{CC}$ ≤ 5.25 V and 0 ≤ $T_A$ ≤ 70°C; typical values are at $T_A$ = 25°C, $V_{CC}$ = 5.0 V)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Bus Voltage<br>(Bus Pin Open) ($V_{I(S/R)}$ = 0.8 V)<br>($I_{(BUS)}$ = –12 mA) | $V_{(BUS)}$<br>$V_{IC(BUS)}$ | 2.75<br>– | –<br>– | 3.7<br>– 1.5 | V |
| Bus Current<br>(5.0 V ≤ $V_{(BUS)}$ ≤ 5.5 V)<br>($V_{(BUS)}$ = 0.5 V)<br>($V_{CC}$ = 0 V, 0 V ≤ $V_{(BUS)}$ ≤ 2.75 V) | $I_{(BUS)}$ | 0.7<br>–1.3<br>– | –<br>–<br>– | 2.5<br>– 3.2<br>+0.04 | mA |
| Receiver Input Hysteresis ($V_{I(S/R)}$ = 0.8 V) | – | 400 | 600 | – | mV |
| Receiver Input Threshold<br>($V_{I(S/R)}$ = 0.8 V, Low to High)<br>($V_{I(S/R)}$ = 0.8 V, High to Low) | $V_{ILH(R)}$<br>$V_{IHL(R)}$ | –<br>0.8 | 1.6<br>1.0 | 1.8<br>– | V |
| Receiver Output Voltage – High Logic State<br>($V_{I(S/R)}$ = 0.8 V, $I_{OH(R)}$ = –800 µA, $V_{(BUS)}$ = 2.0 V) | $V_{OH(R)}$ | 2.7 | – | – | V |
| Receiver Output Voltage – Low Logic State<br>($V_{I(S/R)}$ = 0.8 V, $I_{OL(R)}$ = 16 mA, $V_{(BUS)}$ = 0.8 V) | $V_{OL(R)}$ | – | – | 0.5 | V |
| Receiver Output Short Circuit Current ($V_{I(S/R)}$ = 0.8 V, $V_{(Bus)}$ = 2.0 V) | $I_{OS(R)}$ | – 15 | – | –75 | mA |
| Driver Input Voltage – High Logic State ($V_{I(S/R)}$ = 2.0 V) | $V_{IH(D)}$ | 2.0 | – | – | V |
| Driver Input Voltage – Low Logic State ($V_{I(S/R)}$ = 2.0 V) | $V_{IL(D)}$ | – | – | 0.8 | V |
| Driver Input Current – Data Pins ($V_{I(S/R)}$ = $V_{I(E)}$ = 2.0 V)<br>(0.5 ≤ $V_{I(D)}$ ≤ 2.7 V)<br>($V_{I(D)}$ = 5.5 V) | $I_{I(D)}$<br>$I_{IB(D)}$ | –200<br>– | –<br>– | 40<br>200 | µA |
| Input Current – Send/Receive<br>(0.5 ≤ $V_{I(S/R)}$ ≤ 2.7 V)<br>($V_{I(S/R)}$ = 5.5 V) | $I_{I(S/R)}$<br>$I_{IB(S/R)}$ | –100<br>– | –<br>– | 20<br>100 | µA |
| Input Current – Enable<br>(0.5 ≤ $V_{I(E)}$ ≤ 2.7 V)<br>($V_{I(E)}$ = 5.5 V) | $I_{I(E)}$<br>$I_{IB(E)}$ | –200<br>– | –<br>– | 20<br>100 | µA |
| Driver Input Clamp Voltage ($V_{I(S/R)}$ = 2.0 V, $I_{IC(D)}$ = –18 mA) | $V_{IC(D)}$ | – | – | –1.5 | V |
| Driver Output Voltage – High Logic State<br>($V_{I(S/R)}$ = 2.0 V, $V_{IH(D)}$ = 2.0 V, $V_{IH(E)}$ = 2.0 V, $I_{OH}$ = – 5.2 mA) | $V_{OH(D)}$ | 2.5 | – | – | V |
| Driver Output Voltage – Low Logic State (Note 1)<br>($V_{I(S/R)}$ = 2.0 V, $I_{OL(D)}$ = 48 mA) | $V_{OL(D)}$ | – | – | 0.5 | V |
| Output Short Circuit Current<br>($V_{I(S/R)}$ = 2.0 V, $V_{IH(D)}$ = 2.0 V, $V_{IH(E)}$ = 2.0 V) | $I_{OS(D)}$ | –30 | – | –120 | mA |
| Power Supply Current<br>(Listening Mode – All Receivers On)<br>(Talking Mode – All Drivers On) | $I_{CCL}$<br>$I_{CCH}$ | –<br>– | 63<br>106 | 85<br>125 | mA |

Not Recommended For New Designs

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**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted)

| | | | | | |
|---|---|---|---|---|---|
| Propagation Delay of Driver | | | | | ns |
| (Output Low to High) | $t_{PLH(D)}$ | – | – | 15 | |
| (Output High to Low) | $t_{PHL(D)}$ | – | – | 17 | |
| Propagation Delay of Receiver | | | | | ns |
| (Output Low to High) | $t_{PLH(R)}$ | – | – | 25 | |
| (Output High to Low) | $t_{PHL(R)}$ | – | – | 23 | |

**NOTE:** 1. A modification of the IEEE 488–1978 Bus Standard changes $V_{OL(D)}$ from 0.4 to 0.5 V maximum to permit the use of Schottky technology.

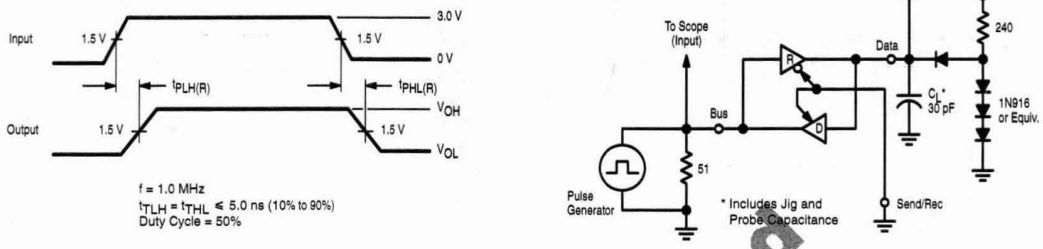
**SWITCHING CHARACTERISTICS (continued)** ($V_{CC}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time – Send/Receive to Data | | | | | ns |
| Logic High to Third State | $t_{PHZ(R)}$ | – | – | 30 | |
| Third State to Logic High | $t_{PZH(R)}$ | – | – | 30 | |
| Logic Low to Third State | $t_{PLZ(R)}$ | – | – | 30 | |
| Third State to Logic Low | $t_{PZL(R)}$ | – | – | 30 | |
| Propagation Delay Time – Send/Receive to Bus | | | | | ns |
| Logic High to Third State | $t_{PHZ(D)}$ | – | – | 30 | |
| Third State to Logic High | $t_{PZH(D)}$ | – | – | 30 | |
| Logic Low to Third State | $t_{PLZ(D)}$ | – | – | 30 | |
| Third State to Logic Low | $t_{PZL(D)}$ | – | – | 30 | |
| Turn–On Time – Enable to Bus | | | | | ns |
| Pull–Up Enable to Open Collector | $t_{POFF(E)}$ | – | – | 30 | |
| Open Collector to Pull–Up Enable | $t_{PON(E)}$ | – | – | 20 | |

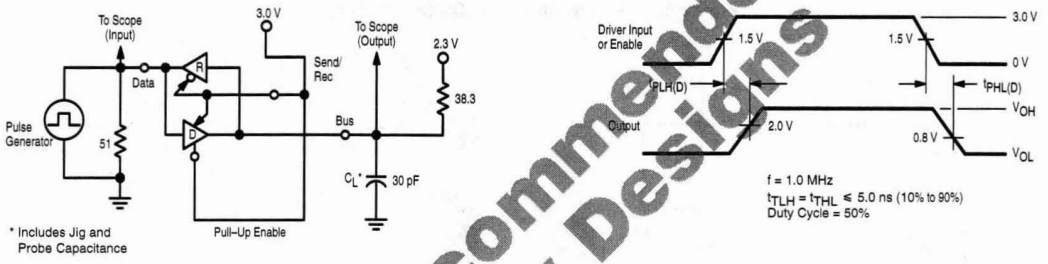
Not Recommended For New Designs

## PROPAGATION DELAY TEST CIRCUITS AND WAVEFORMS

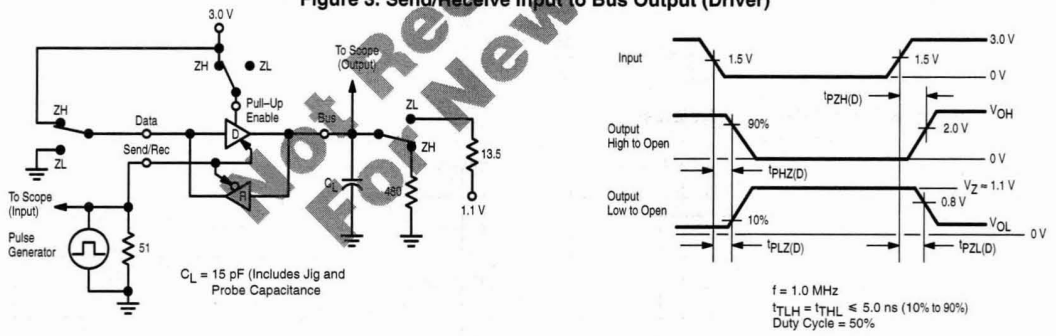
### Figure 1. Bus Input to Data Output (Receiver)




### Figure 2. Data Input to Bus Output (Driver)




### Figure 3. Send/Receive Input to Bus Output (Driver)




Not Recommended For New Designs

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**Figure 4. Send/Receive Input to Data Output (Receiver)**

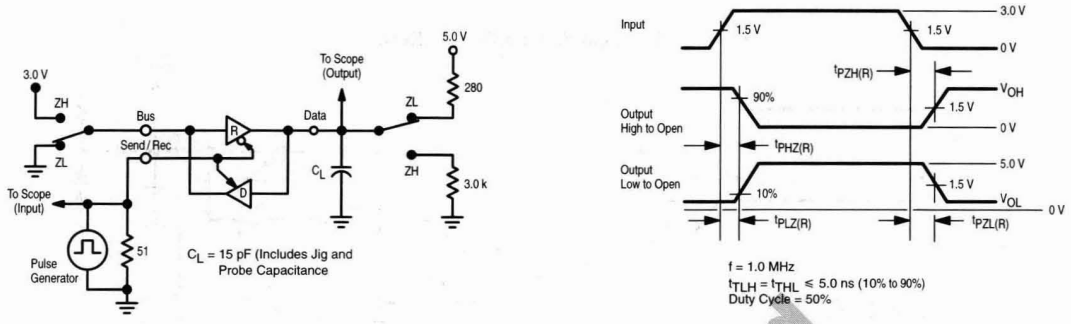
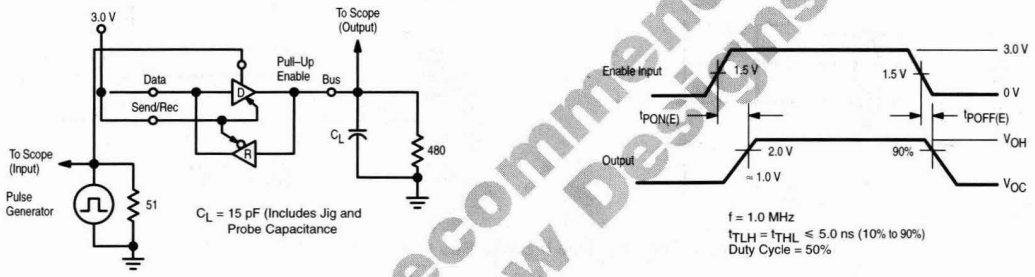



**Figure 5. Enable Input to Bus Output (Driver)**




Not Recommended For New Designs

**Figure 6. Typical Receiver Hysteresis Characteristics**

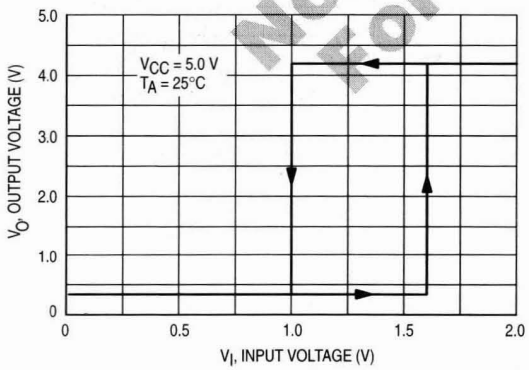



**Figure 7. Typical Bus Load Line**

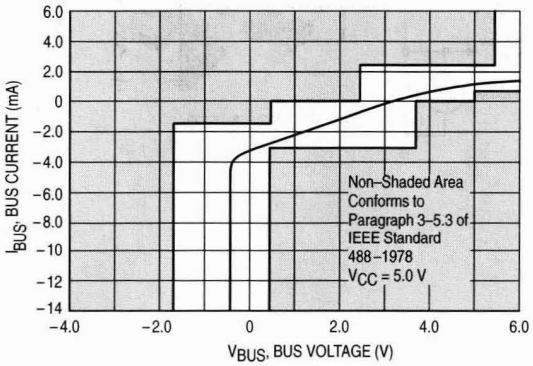
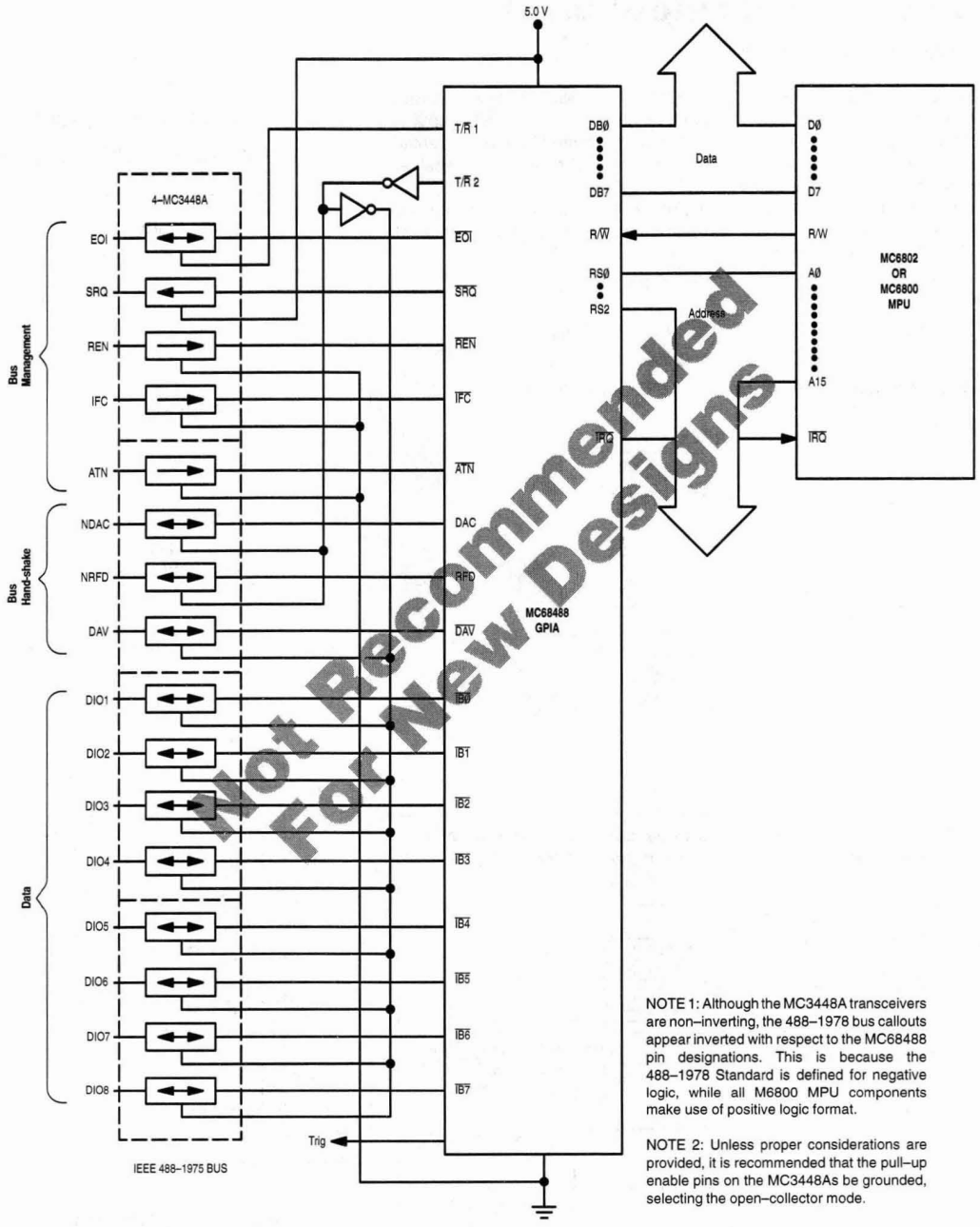


**Figure 8. Simple System Configuration**




NOTE 1: Although the MC3448A transceivers are non–inverting, the 488–1978 bus callouts appear inverted with respect to the MC68488 pin designations. This is because the 488–1978 Standard is defined for negative logic, while all M6800 MPU components make use of positive logic format.

NOTE 2: Unless proper considerations are provided, it is recommended that the pull–up enable pins on the MC3448As be grounded, selecting the open–collector mode.

Not Recommended For New Designs

7

MOTOROLA

# MC3450

# Quad MTTL Compatible Line Receivers

**QUAD LINE RECEIVERS WITH COMMON THREE–STATE STROBE INPUT**

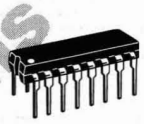
**SEMICONDUCTOR TECHNICAL DATA**

The MC3450 features four MC75107 type active pullup line receivers with the addition of a common three–state strobe input. When the strobe input is at a logic zero, each receiver output state is determined by the differential voltage across its respective inputs. With the strobe high, the receiver outputs are in the high impedance state.

The strobe input on both devices is buffered to present a strobe loading factor of only one for all four receivers and inverted to provide best compatability with standard decoder devices.

- Receiver Performance Identical to the Popular MC75107/MC75108 Series
- Four Independent Receivers with Common Strobe Input
- Implied "AND" Capability with Open Collector Outputs
- Useful as a Quad 1103 type Memory Sense Amplifier

Not Recommended For New Designs



**P SUFFIX**
PLASTIC PACKAGE
CASE 648

**TRUTH TABLE**

| Input | Strobe | Output MC3450 |
|---|---|---|
| $V_{ID} \geq +25$ mV | L | H |
| | H | Z |
| $-25$ mV $\leq V_{ID} \leq +25$ mV | L | I |
| | H | Z |
| $V_{ID} \leq -25$ mV | L | L |
| | H | Z |

L = Low Logic State
H = High Logic State
Z = Third (High Impedance) State
I = Indeterminate State

**PIN CONNECTIONS**

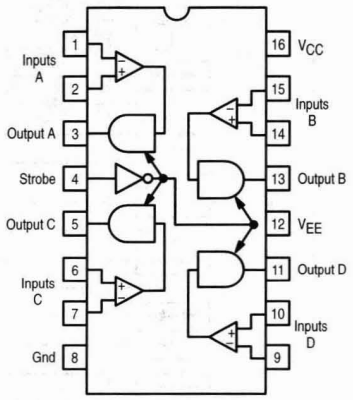
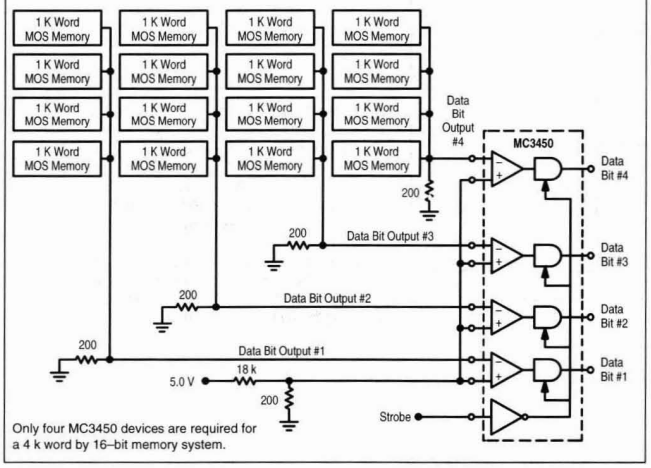



**Figure 1. A Typical MOS Memory Sensing Application for a 4 k Word by 4–Bit Memory Arrangement Employing 1103 Type Memory Devices**




Only four MC3450 devices are required for a 4 k word by 16–bit memory system.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3450P | $T_A$ = 0 to +70°C | Plastic DIP |

**MAXIMUM RATINGS** ($T_A$ = 0 to +70°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltages | $V_{CC}$, $V_{EE}$ | ±7.0 | Vdc |
| Differential Mode Input Signal Voltage Range | $V_{IDR}$ | ±6.0 | Vdc |
| Common Mode Input Voltage Range | $V_{ICR}$ | ±5.0 | Vdc |
| Strobe Input Voltage | $V_{I(S)}$ | 5.5 | Vdc |
| Power Dissipation (Package Limitation)<br>Ceramic Dual In–Line Package<br>Derate above $T_A$ = 25°C<br>Plastic Dual In–Line Package<br>Derate above $T_A$ = 25°C | $P_D$ | <br>1000<br>6.6<br>1000<br>6.6 | <br>mW<br>mW/°C<br>mW<br>mW/°C |
| Operating Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**RECOMMENDED OPERATING CONDITIONS** ($T_A$ = 0 to +70°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltages | $V_{CC}$<br>$V_{EE}$ | +4.75<br>–4.75 | +5.0<br>–5.0 | +5.25<br>–5.25 | Vdc |
| Output Load Current | $I_{OL}$ | – | – | 16 | mA |
| Differential Mode Input Voltage Range | $V_{IDR}$ | –5.0 | – | +5.0 | Vdc |
| Common Mode Input Voltage Range | $V_{ICR}$ | –3.0 | – | +3.0 | Vdc |
| Input Voltage Range (any input to Ground) | $V_{IR}$ | –5.0 | – | +3.0 | Vdc |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = +5.0 Vdc, $V_{EE}$ = –5.0 Vdc, $T_A$ = 0 to +70°C, unless otherwise noted.)

| Characteristic | Symbol | MC3450 Min | MC3450 Typ | MC3450 Max | Unit |
|---|---|---|---|---|---|
| High Level Input Current to Receiver Input | $I_{IH(I)}$ | – | – | 75 | µA |
| Low Level Input Current to Receiver Input | $I_{IL(I)}$ | – | – | –10 | µA |
| High Level Input Current to Strobe Input<br>$V_{IH(S)}$ = 2.4 V<br>$V_{IH(S)}$ = 5.25 V | $I_{IH(S)}$ | <br>–<br>– | <br>–<br>– | <br>40<br>1.0 | <br>µA<br>mA |
| Low Level Input Current to Strobe Input<br>$V_{IL(S)}$ = 0.4 V | $I_{IL(S)}$ | – | – | –1.6 | mA |
| High Level Output Voltage | $V_{OH}$ | 2.4 | – | – | Vdc |
| High Level Output Leakage Current | $I_{CEX}$ | – | – | – | µA |
| Low Level Output Voltage | $V_{OL}$ | – | – | 0.5 | Vdc |
| Short–Circuit Output Current | $I_{OS}$ | –18 | – | –70 | mA |
| Output Disable Leakage Current | $I_{off}$ | – | – | 40 | µA |
| High Logic Level Supply Current from $V_{CC}$ | $I_{CCH}$ | – | 45 | 60 | mA |
| High Logic Level Supply Current from $V_{EE}$ | $I_{EEH}$ | – | –17 | –30 | mA |

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = +5.0 Vdc, $V_{EE}$ = –5.0 Vdc, $T_A$ = +25°C, unless otherwise noted.)

| Characteristic | Symbol | MC3450 Min | MC3450 Typ | MC3450 Max | Unit |
|---|---|---|---|---|---|
| High to Low Logic Level Propagation Delay Time (Differential Inputs) | $t_{PHL(D)}$ | – | – | 25 | ns |
| Low to High Logic Level Propagation Delay Time (Differential Inputs) | $t_{PLH(D)}$ | – | – | 25 | ns |
| Open State to High Logic Level Propagation Delay Time (Strobe) | $t_{PZH(S)}$ | – | – | 21 | ns |
| High Logic Level to Open State Propagation Delay Time (Strobe) | $t_{PHZ(S)}$ | – | – | 18 | ns |
| Open State to Low Logic Level Propagation Delay Time (Strobe) | $t_{PZL(S)}$ | – | – | 27 | ns |
| Low Logic Level to Open State Propagation Delay Time (Strobe) | $t_{PLZ(S)}$ | – | – | 29 | ns |
| High Logic to Low Logic Level Propagation Delay Time (Strobe) | $t_{PHL(S)}$ | – | – | – | ns |
| Low Logic to High Logic Level Propagation Delay Time (Strobe) | $t_{PLH(S)}$ | – | – | – | ns |

Not Recommended For New Designs

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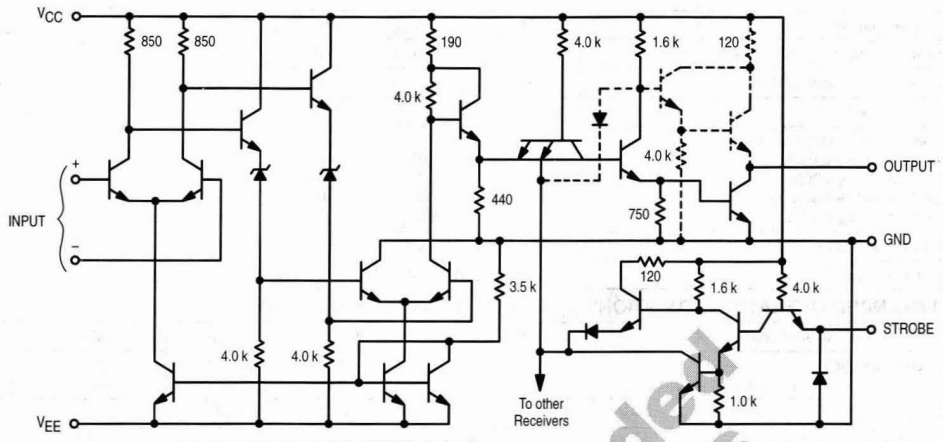
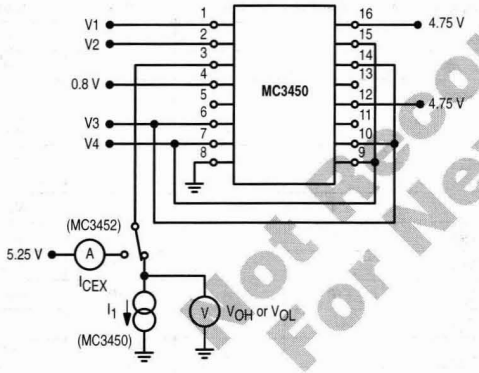
**Figure 2. Circuit Schematic**
(1/4 Circuit Shown)




Dashed components apply to the MC3450 circuit only.

## TEST CIRCUITS

**Figure 3. $I_{CEX}$, $V_{OH}$, and $V_{OL}$**




**TEST TABLE**

| | V1 | V2 | V3 | V4 | |
|---|---|---|---|---|---|
| | MC3450 | MC3450 | MC3450 | MC3450 | I1 |
| $V_{OH}$ | 2.975 V | 3.0 V | 3.0 V | GND | 0.4 mA |
| | –3.0 V | –2.975 V | GND | –3.0 V | |
| $I_{CEX}$ | | – | – | – | – |
| | | – | – | – | – |
| $V_{OL}$ | 3.0 V | 2.975 V | GND | 3.0 V | –16 mA |
| | –2.975 V | –3.0V | –3.0 V | GND | |

Channel A shown under test. Other channels are tested similarly.

**Figure 4. $I_{CCH}$ and $I_{EEH}$**

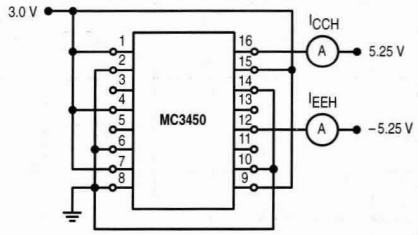
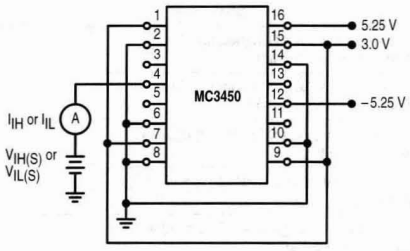


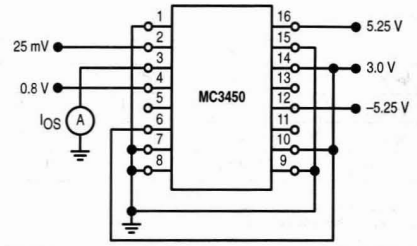

**Figure 5. $I_{IH(S)}$ and $I_{IL(S)}$**




Not Recommended For New Designs

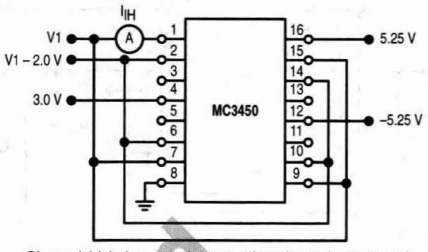
## TEST CIRCUITS (continued)

### Figure 6. $I_{OS}$



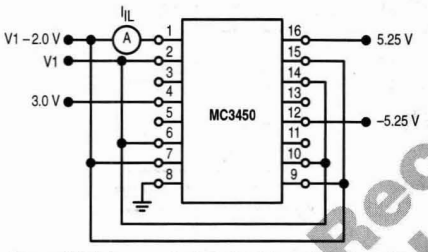

Channel A shown under test, other channels are tested similarly.
Only one output shorted at a time.

### Figure 7. $I_{IH}$



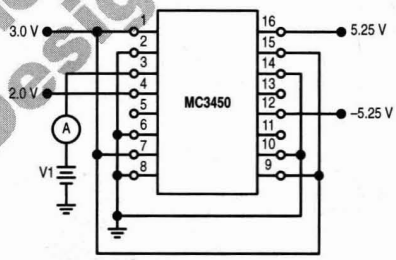

Channel A(–) shown under test, other channels are tested similarly. Devices are tested with V1 from 3.0 V to –3.0 V.

### Figure 8. $I_{IL}$




Channel A(–) shown under test, other channels are tested similarly. Devices are tested with V1 from 3.0 V to –3.0 V.

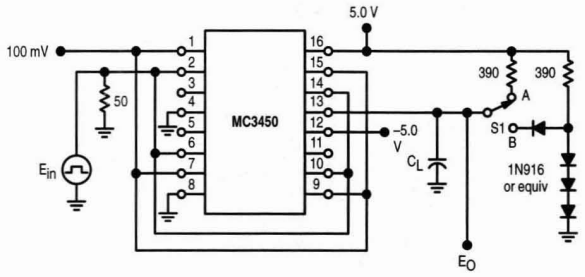
### Figure 9. $I_{off}$

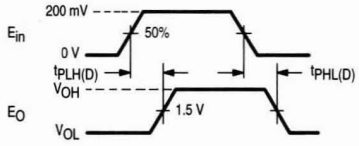



Output of Channel A shown under test, other outputs are tested similarly for V1 = 0.4 V and 2.4 V.

Not Recommended For New Designs

### Figure 10. Receiver Propagation Delay $t_{PLH(D)}$ and $t_{PHL(D)}$



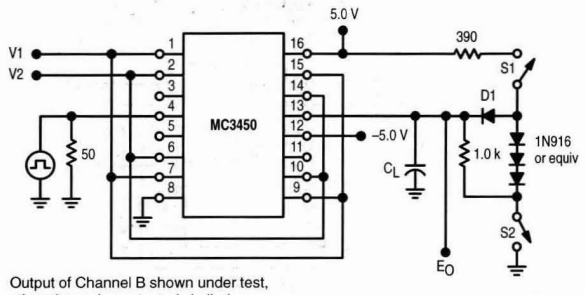




Output of Channel B shown under test, other channels are tested similarly.
S1 at "A" for MC3452
S1 at "B" for MC3450
$C_L$ = 15 pF total for MC3452
$C_L$ = 50 pF total for MC3450

$E_{in}$ waveform characteristics:
$t_{TLH}$ and $t_{THL} \leq$ 10 ns measured 10% to 90%
PRR = 1.0 MHz
Duty Cycle = 500 ns

**TEST CIRCUITS** (continued)

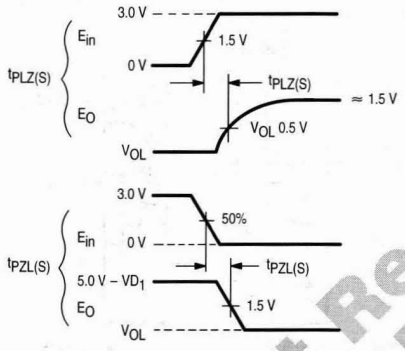
**Figure 11. Strobe Propagation Delay Times $t_{PLZ(S)}$ $t_{PZL(S)}$ $t_{PHZ(S)}$ and $t_{PZH(S)}$**

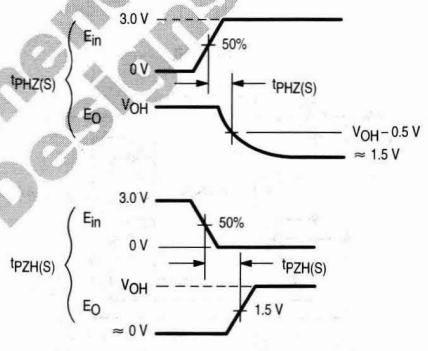



Output of Channel B shown under test,
other channels are tested similarly.

| | V1 | V2 | S1 | S2 | $C_L$ |
|---|---|---|---|---|---|
| $t_{PLZ(S)}$ | 100 mV | GND | Closed | Closed | 15 pF |
| $t_{PZL(S)}$ | 100 mV | GND | Closed | Open | 50 pF |
| $t_{PHZ(S)}$ | GND | 100 mV | Closed | Closed | 15 pF |
| $t_{PZH(S)}$ | GND | 100 mV | Open | Closed | 50 pF |

$C_L$ includes jig and probe capacitance.
$E_{in}$ waveform characteristics:
$t_{TLH}$ and $t_{THL}$ ≤ 10 ns measured 10% to 90%.
PRR = 1.0 MHz
Duty Cycle = 50%

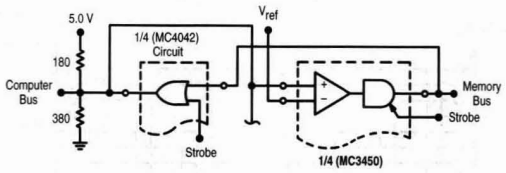



Not Recommended For New Designs

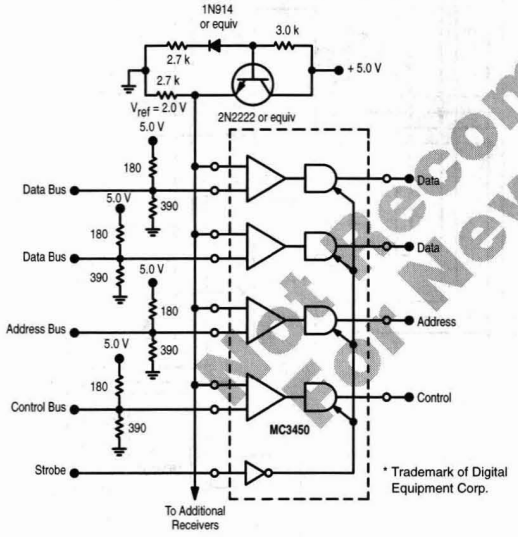
## APPLICATIONS INFORMATION

### Figure 12. Bidirectional Data Transmission




The three–state capability of the MC3450 permits bidirectional data transmission as illustrated.

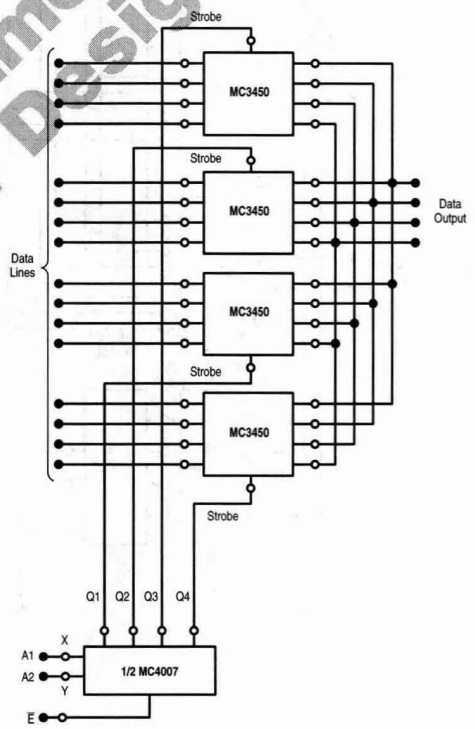
### Figure 13. Single–Ended Uni–Bus™ Line Receiver Application for Minicomputer




* Trademark of Digital Equipment Corp.

The MC3450 can be used for single–ended as well as differential line receiving. For single–ended line receiver applications, such as are encountered in minicomputers, the configuration shown in Figure 15 can be used. The voltage source, which generates $V_{ref}$, should be designed so that the $V_{ref}$ voltage is halfway between $V_{OH}$(min) and $V_{OL}$(max). The maximum input overdrive required to guarantee a given logic state is extremely small, 25 mV maximum. This low–input overdrive enhances differential noise immunity. Also the high–input impedance of the line receiver permits many receivers to be placed on a single line with minimum load effects.

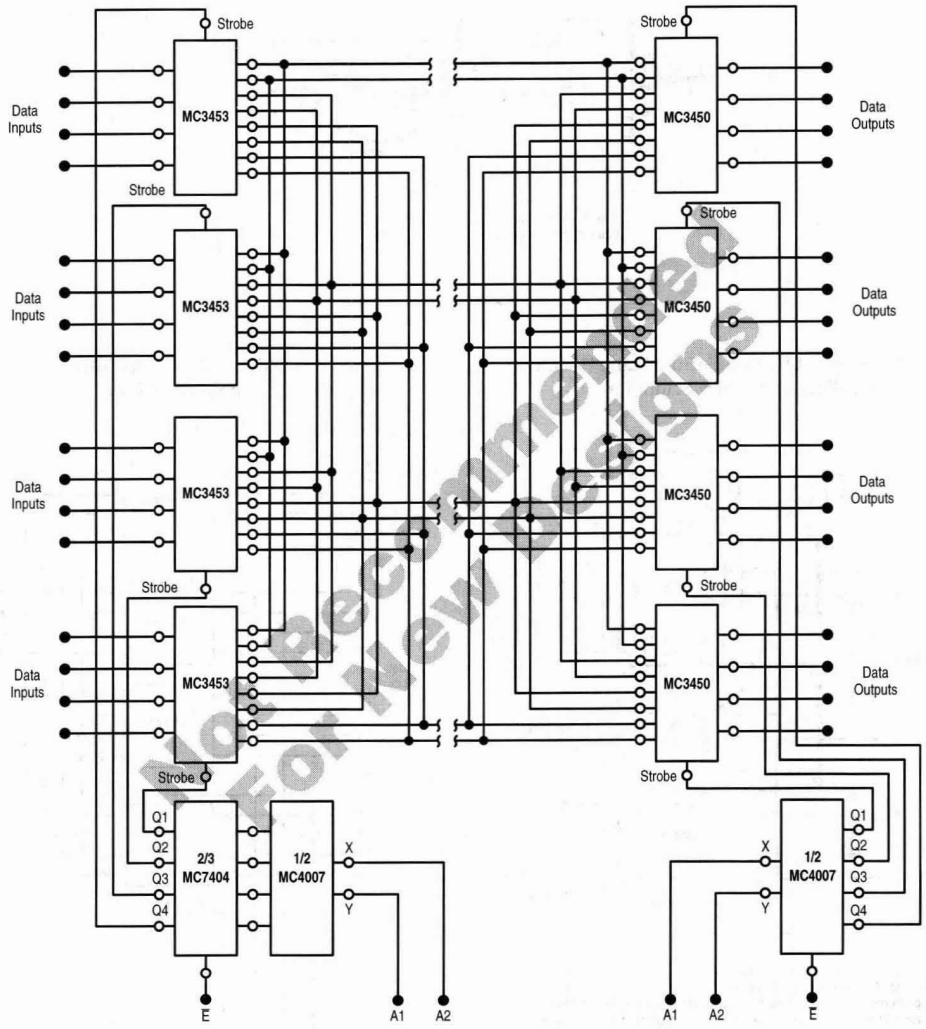
### Figure 14. Wired "OR" Data Selection Using Three–State Logic




Not Recommended For New Designs

**APPLICATIONS INFORMATION** (continued)

**Figure 15. Party–Line Data Transmission System with Multiplex Decoding**




Not Recommended For New Designs

MOTOROLA

# MC3453

# MTTL Compatible Quad Line Driver

The MC3453 features four SN75110 type line drivers with a common inhibit input. When the inhibit input is high, a constant output current is switched between each pair of output terminals in response to the logic level at that channel's input. When the inhibit is low, all channel outputs are nonconductive (transistors biased to cut–off). This minimizes loading in party–line systems where a large number of drivers share the same line.

- Four Independent Drivers with Common Inhibit Input
- – 3.0 V Output Common–Mode Voltage Over Entire Operating Range
- Improved Driver Design Exceeds Performance of Popular SN75110

**QUAD LINE DRIVER WITH COMMON INHIBIT INPUT**

**SEMICONDUCTOR TECHNICAL DATA**

**P SUFFIX**
PLASTIC PACKAGE
CASE 648

Not Recommended For New Designs

**PIN CONNECTIONS**

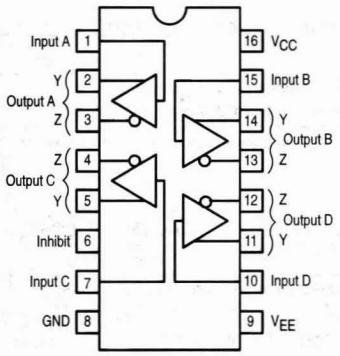
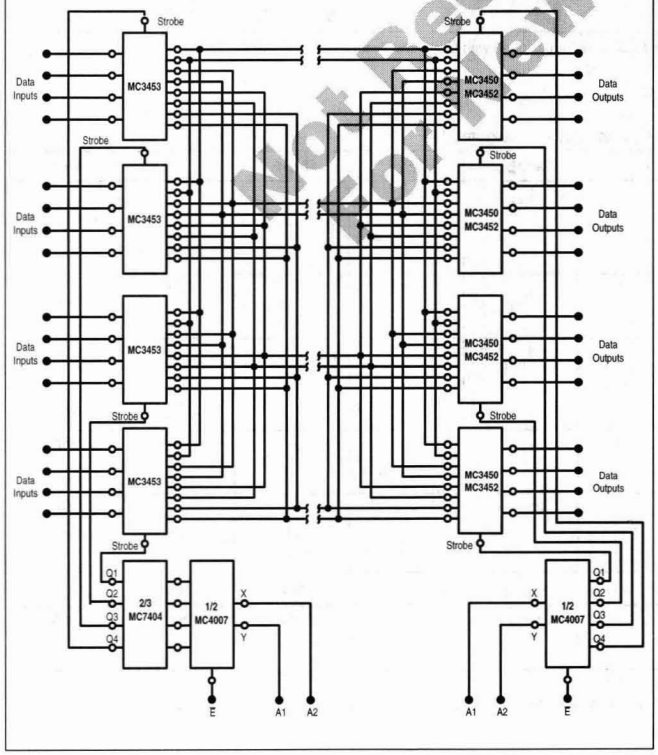



**Figure 1. Party–Line Data Transmission System with Multiplex Decoding**




**TRUTH TABLE**
**(positive logic)**

| Logic Input | Inhibit Input | Output Current | |
|---|---|---|---|
| | | Z | Y |
| H | H | On | Off |
| L | H | Off | On |
| H | L | Off | Off |
| L | L | Off | Off |

L = Low Logic Level
H = High Logic Level

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3453P | $T_A$ = 0 to +70°C | Plastic DIP |

7

**MAXIMUM RATINGS** ($T_A$ = 0 to +70°C, unless otherwise noted.)

| | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | +7.0 | V |
| | $V_{EE}$ | –7.0 | |
| Logic and Inhibitor Input Voltages | $V_{in}$ | 5.5 | V |
| Common–Mode Output Voltage Range | $V_{OCR}$ | –5.0 to +12 | V |
| Power Dissipation (Package Limitation) | $P_D$ | | |
| Plastic Dual In–Line Package | | 1000 | mW |
| Derate above $T_A$ = 25°C | | 6.6 | mW/°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range<br>Plastic and Ceramic Dual In–Line Packages | $T_{stg}$ | –65 to +150 | °C |

**RECOMMENDED OPERATING CONDITIONS** (See Notes 1 and 2.)

| Characteristic | Symbol | Min | Nom | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltages | $V_{CC}$ | +4.75 | +5.0 | +5.25 | V |
| | $V_{EE}$ | –4.75 | –5.0 | –5.25 | |
| Common–Mode Output Voltage Range | $V_{OCR}$ | | | | V |
| Positive | | 0 | – | +10 | |
| Negative | | 0 | – | –3.0 | |

**NOTES:** 1. These voltage values are in respect to the ground terminal.
2. When not using all four channels, unused outputs **must** be grounded.

7

**DEFINITIONS OF INPUT LOGIC LEVELS***

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| High–Level Input Voltage (at any input) | $V_{IH}$ | 2.0 | 5.5 | V |
| Low–Level Input Voltage (at any input) | $V_{IL}$ | 0 | 0.8 | V |

* The algebraic convention, where the most positive limit is designated maximum, is used with Logic Level Input Voltage Levels only.

Not Recommended For New Designs

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 0 to +70°C, unless otherwise noted.)

| Characteristic## | Symbol | Min | Typ# | Max | Unit |
|---|---|---|---|---|---|
| High–Level Input Current (Logic Inputs) | $I_{IH_L}$ | | | | |
| ($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IH_L}$ = 2.4 V) | | – | – | 40 | μA |
| ($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IH_L}$ = $V_{CC}$ Max) | | – | – | 1.0 | mA |
| Low–Level Input Current (Logic Inputs)<br>($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IL_L}$ = 0.4 V) | $I_{IL_L}$ | – | – | –1.6 | mA |
| High–Level Input Current (Inhibit Input) | $I_{IH_I}$ | | | | |
| ($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IH_I}$ = 2.4 V) | | | | | |
| ($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IH_I}$ = $V_{CC}$ Max) | | – | – | 40 | μA |
| Low–Level Input Current (Inhibit Input)<br>($V_{CC}$ = Max, $V_{EE}$ = Max, $V_{IL_I}$ = 0.4 V) | $I_{IL_I}$ | – | – | –1.6 | mA |
| Output Current ("ON" state) | $I_{O(on)}$ | | | | mA |
| ($V_{CC}$ = Max, $V_{EE}$ = Max) | | – | 11 | 15 | |
| ($V_{CC}$ = Min, $V_{EE}$ = Min) | | 6.5 | 11 | – | |
| Output Current ("OFF" state) ($V_{CC}$ = Min, $V_{EE}$ = Min) | $I_{O(off)}$ | – | 5.0 | 100 | μA |
| Supply Current from $V_{CC}$ (with driver enabled)<br>($V_{IL_L}$ = 0.4 V, $V_{IH_I}$ = 2.0 V) | $I_{CC(on)}$ | – | 35 | 50 | mA |

#All typical values are at $V_{CC}$ = 5.0 V, $V_{EE}$ = –5.0 V, $T_A$ = 25°C.
##For conditions shown as Min or Max, use the appropriate value specified under recommended operating conditions for the applicable device type. Ground unused inputs and outputs.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 0 to +70°C, unless otherwise noted.)

| Characteristic## | Symbol | Min | Typ# | Max | Unit |
|---|---|---|---|---|---|
| Supply Current from $V_{EE}$ (with driver enabled) ($V_{IL_L}$ = 0.4 V, $V_{IH_I}$ = 2.0 V) | $I_{EE(on)}$ | – | 65 | 90 | mA |
| Supply Current from $V_{CC}$ (with driver inhibited) ($V_{IL_L}$ = 0.4 V, $V_{IL_I}$ = 0.4 V) | $I_{CC(off)}$ | – | 35 | 50 | mA |
| Supply Current from $V_{EE}$ (with driver inhibited) ($V_{IL_L}$ = 0.4 V, $V_{IL_I}$ = 0.4 V) | $I_{EE(off)}$ | – | 25 | 40 | mA |

#All typical values are at $V_{CC}$ = 5.0 V, $V_{EE}$ = –5.0 V, $T_A$ = 25°C.
##For conditions shown as Min or Max, use the appropriate value specified under recommended operating conditions for the applicable device type.
Ground unused inputs and outputs.

**SWITCHING CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $V_{EE}$ = –5.0 V, $T_A$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time from Logic Input to Output Y or Z ($R_L$ = 50 ohms, $C_L$ = 40 pF) | $t_{PLH_L}$<br>$t_{PHL_L}$ | –<br>– | 9.0<br>9.0 | 17<br>17 | ns |
| Propagation Delay time from Inhibit Input to Output Y or Z ($R_L$ = 50 ohms, $C_L$ = 40 pF) | $t_{PLH_I}$<br>$t_{PHL_I}$ | –<br>– | 20<br>16 | 25<br>25 | ns |

Not Recommended For New Designs

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**Figure 2. Logic Input to Outputs Propagation Delay Time Waveforms**

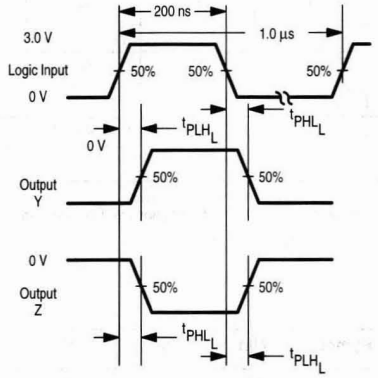
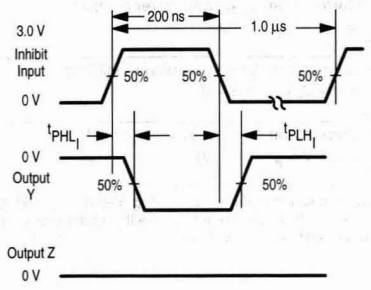
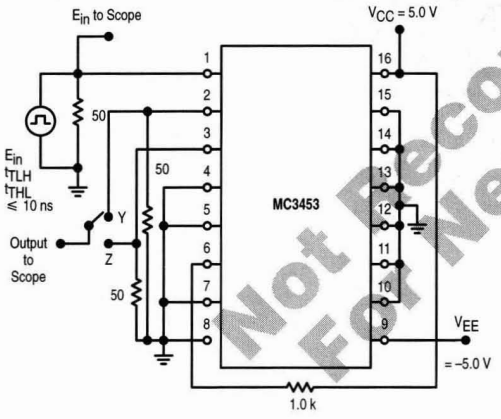



**Figure 3. Inhibit Input to Outputs Propagation Delay Time Waveforms**



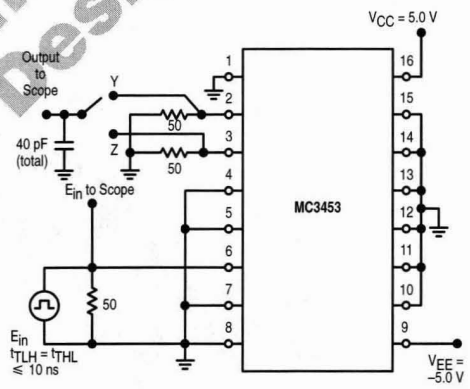

## TEST CIRCUITS

**Figure 4. Logic Input to Output Propagation Delay Time Test Circuit**




Channel A shown under test, the other channels are tested similarly.

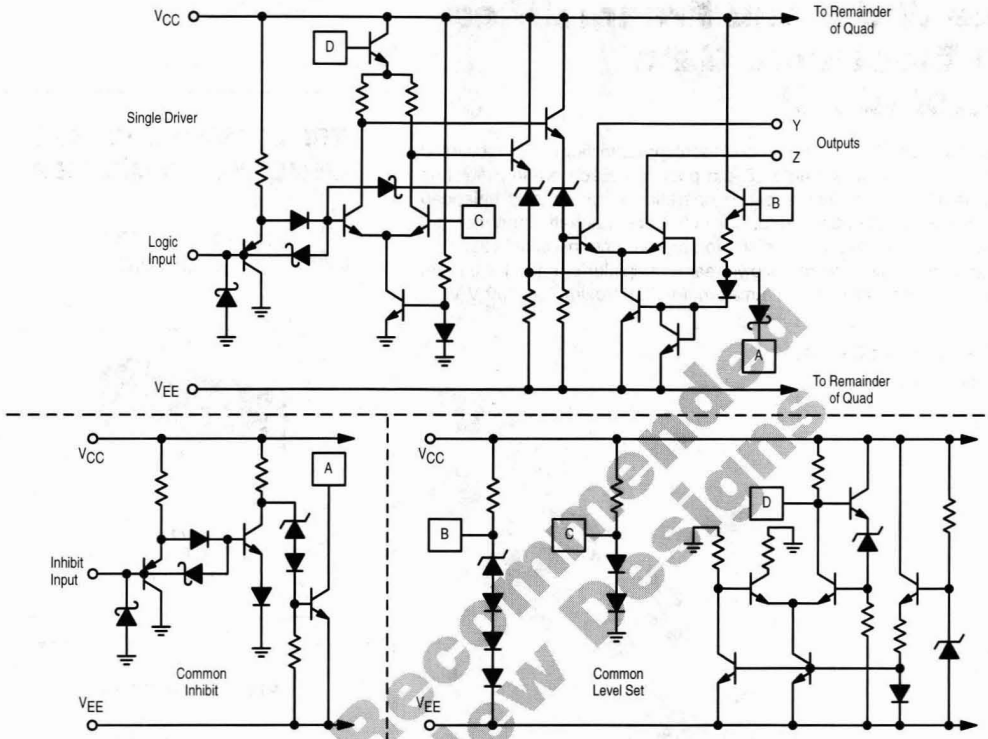
**Figure 5. Inhibit Input to Output Propagation Delay time Test Circuit**




Channel A shown under test, the other channels are tested similarly.

Not Recommended For New Designs

**Figure 6. Circuit Schematic**
(1/4 Circuit Shown)




Not Recommended For New Designs

MOTOROLA

# MC3467

## Triple Wideband Preamplifier with Electronic Gain Control (EGC)

The MC3467 provides three independent preamplifiers with individual electronic gain control in a single 18–pin package. Each preamplifier has differential inputs and outputs allowing operation in completely balanced systems. The device is optimized for use in 9–track magnetic tape memory systems where low noise and low distortion are paramount objectives.

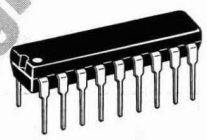
The electronic gain control allows each amplifier's gain to be set anywhere from essentially zero to a maximum of approximately 100 V/V.

- Wide Bandwidth – 15 MHz (Typical)
- Individual Electronic Gain Control
- Differential Input/Output

**TRIPLE MAGNETIC TAPE MEMORY PREAMPLIFIER**

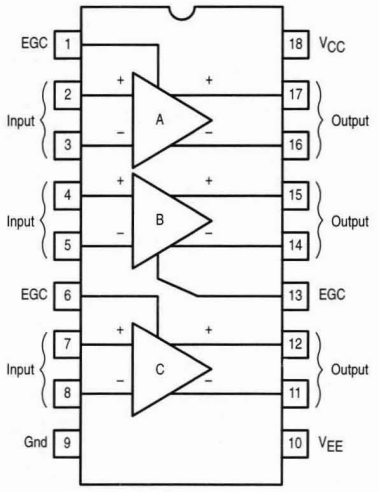
**SEMICONDUCTOR TECHNICAL DATA**

Not Recommended For New Designs

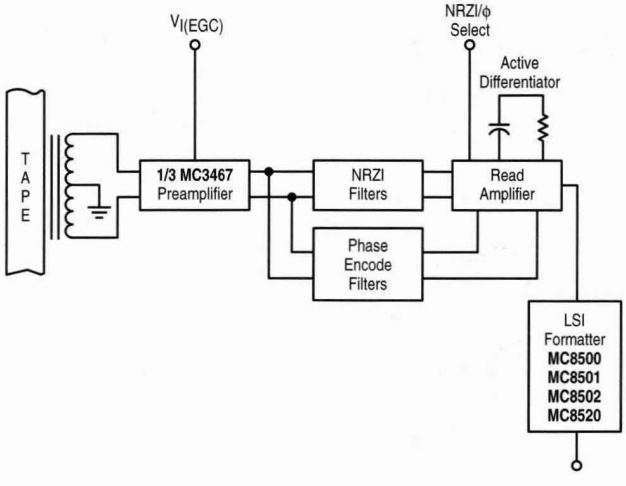


**P SUFFIX**
PLASTIC PACKAGE
CASE 707

**PIN CONNECTIONS**




**Simplified Application**
**High Performance 9–Track Open Reel Tape System**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3467P | $T_A$ = 0 to +70°C | Plastic DIP |

7

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltages<br>Positive Supply Voltage<br>Negative Supply Voltage | <br>$V_{CC}$<br>$V_{EE}$ | <br>6.0<br>–9.0 | V |
| EGC Voltages (Pins 1, 6 and 13) | $V_{I(EGC)}$ | –5.0 to $V_{CC}$ | V |
| Input Differential Voltage | $V_{ID}$ | ± 5.0 | V |
| Input Common–Mode Voltage | $V_{IC}$ | ± 5.0 | V |
| Amplifier Output Short Circuit Duration (to Ground) | $t_{sc}$ | 10 | s |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to +150 | °C |
| Junction Temperature | $T_J$ | +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $V_{EE}$ = –6.0 V, f =100 kHz, $T_A$ = 0 to +70°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage Range<br>Positive Supply Voltage<br>Negative Supply Voltage<br>Operating EGC Voltage | <br>$V_{CCR}$<br>$V_{EER}$<br>$V_{I(EGC)}$ | <br>4.75<br>–5.5<br>0 | <br>5.0<br>–6.0<br>– | <br>5.25<br>–7.0<br>$V_{CC}$ | V |
| Differential Voltage Gain (Balanced)<br>($V_{I(EGC)}$ = 0, $e_i$ = 25 mVpp) (See Figure 1) | $A_{VD}$ | 85 | 100 | 120 | V/V |
| Differential Voltage Gain<br>($V_{I(EGC)}$ = $V_{CC}$) | $A_{VD}$ | – | 0.5 | 2.0 | V/V |
| Maximum Input Differential Voltage (Balanced) ($T_A$ = 25°C) | $V_{IDR}$ | 0.2 | – | – | $V_{pp}$ |
| Output Voltage Swing (Balanced) (Figure 1)<br>($e_i$ = 200 mVpp) | $V_{OR}$ | 6.0 | 8.0 | – | $V_{pp}$ |
| Input Common–Mode Range | $V_{ICR}$ | ± 1.5 | ± 2.0 | – | V |
| Differential Output Offset Voltage ($T_A$ = 25°C) | $V_{OOD}$ | – | 500 | – | mV |
| Common–Mode Output Offset Voltage ($T_A$ = 25°C) | $V_{OOC}$ | – | 500 | – | mV |
| Common–Mode Rejection Ratio (Figure 2)<br>$V_{I(EGC)}$ = 0, $V_{CM}$ = 1.0 $V_{pp}$<br>(f = 100 kHz)<br>(f = 1.0 MHz) | CMRR | <br><br>60<br>40 | <br><br>100<br>100 | <br><br>–<br>– | dB |
| Small–Signal Bandwidth (Figure 1)<br>(–3.0 dB, $e_i$ = 1.0 mVpp, $T_A$ = 25°C) | BW | 10 | 15 | – | MHz |
| Input Bias Current | $I_{IB}$ | – | 5.0 | 15 | μA |
| Output Sink Current (Figure 5) | $I_{OS}$ | 1.0 | 1.4 | – | mA |
| Differential Noise Voltage Referred to Input (Figure 3)<br>($V_{I(EGC)}$ = 0, $R_S$ = 50 Ω, BW = 10 Hz to 1.0 MHz, $T_A$ = 25°C) | $e_n$ | – | 3.5 | – | $\mu V_{RMS}$ |
| Positive Power Supply Current (Figure 4) | $I_{CC}$ | – | 30 | 40 | mA |
| Negative Power Supply Current (Figure 4) | $I_{EE}$ | – | –30 | –40 | mA |
| Input Resistance ($T_A$ = 25°C) | $r_i$ | 12 | 25 | – | kΩ |
| Input Capacitance ($T_A$ = 25°C) | $C_i$ | – | 2.0 | – | pF |
| Output Resistance (Unbalanced)<br>($T_A$ = 25°C) | $r_o$ | – | 30 | – | Ohms |

Not Recommended For New Designs

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**Figure 1. Differential Voltage Gain, Bandwidth and Output Voltage Swing Test Circuit**
(Channel A under test, other channels tested similarly)

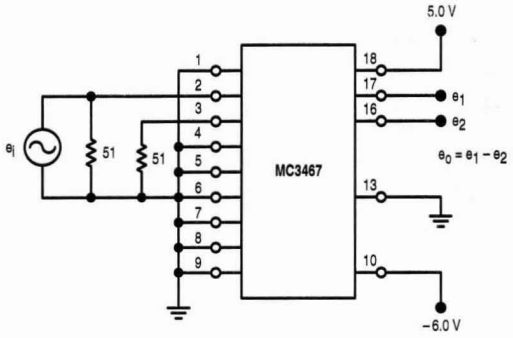



**Figure 2. Common–Mode Rejection Ratio**
(Channel A under test, other amplifiers tested similarly)

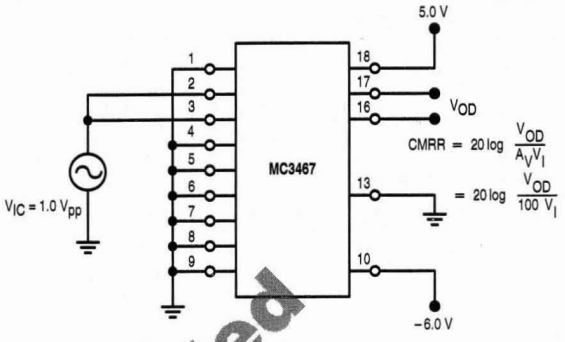
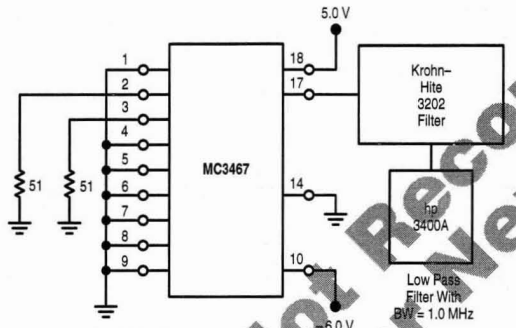



**Figure 3. Differential Noise Voltage Referred to the Input**




Assume Uncorrelated Noise Sources
$e_n$ (Differential Noise at Input) = $e_o \sqrt{2}/100$

**Figure 4. Power Supply Current Test Circuit**

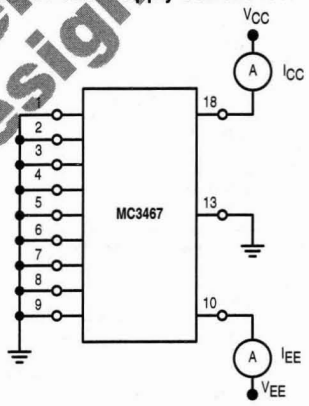



**Figure 5. Output Sink Current Test Circuit**
(Channel A under test, other channels tested similarly)

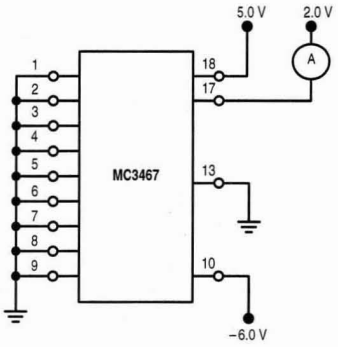
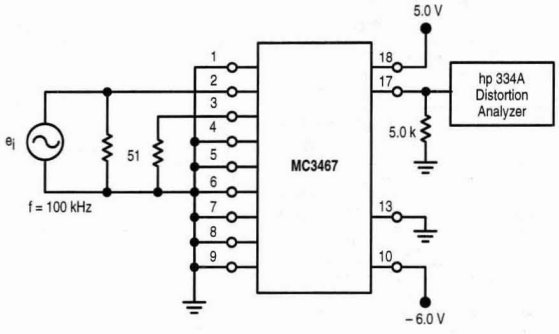



**Figure 6. Total Harmonic Distortion Test Circuit**
(Channel A under test, other channels tested similarly)




Not Recommended For New Designs

## TYPICAL CHARACTERISTICS
($V_{CC}$ = 5.0 V, $V_{EE}$ = –6.0V, $T_A$ = 25° unless otherwise noted)

**Figure 7. Total Harmonic Distortion (THD) versus Input Voltage**

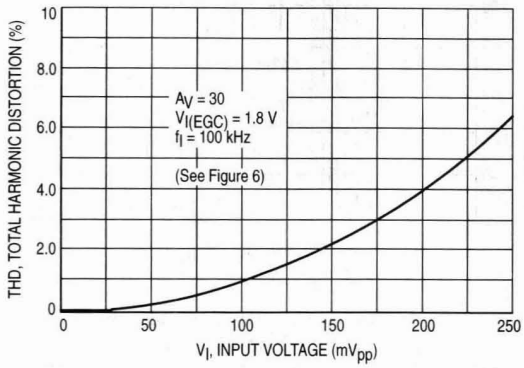



**Figure 8. Normalized Voltage Gain versus Frequency**

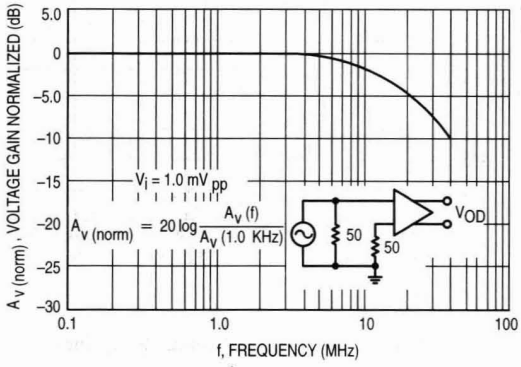



**Figure 9. Normalized Voltage Gain versus Ambient Temperature**

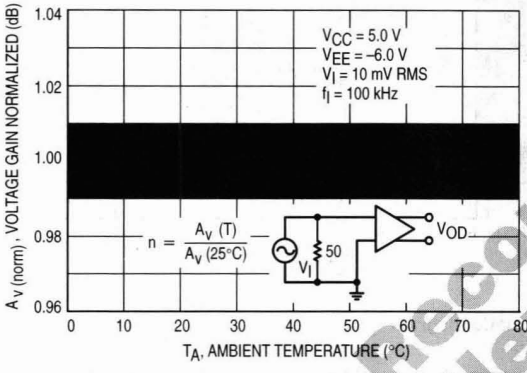



**Figure 10. Normalized Positive Power Supply Current versus Positive Power Supply Voltage**

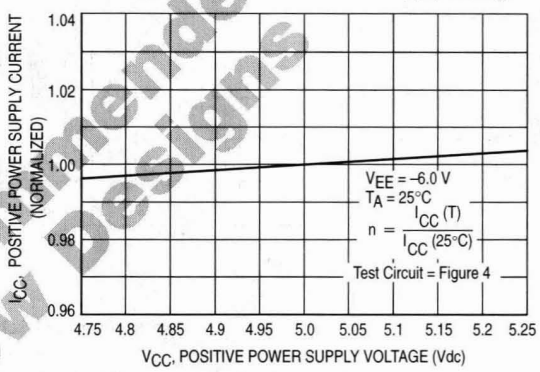



**Figure 11. Normalized Negative Power Supply Current versus Negative Power Supply Voltage**

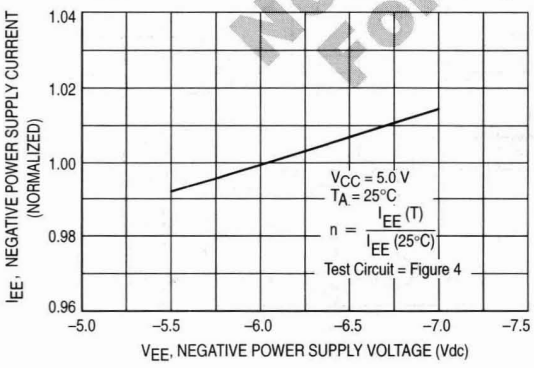
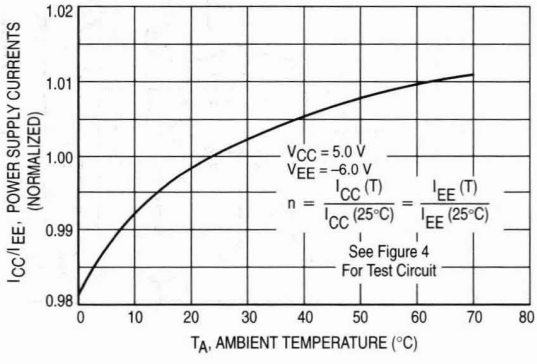



**Figure 12. Normalized Power Supply Currents versus Ambient Temperature**




Not Recommended For New Designs

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**Figure 13. Differential Voltage Gain versus Electronic Gain Control Voltage ($V_{I(EGC)}$)**

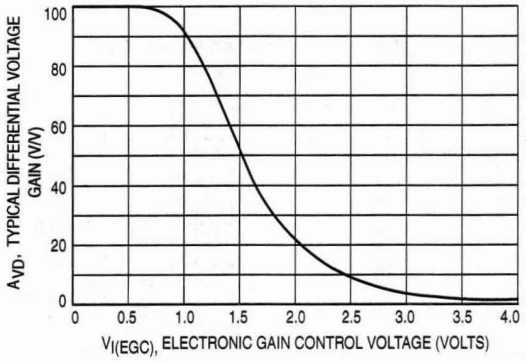



**Figure 14. Common–Mode Rejection Ratio (CMRR) versus Frequency**

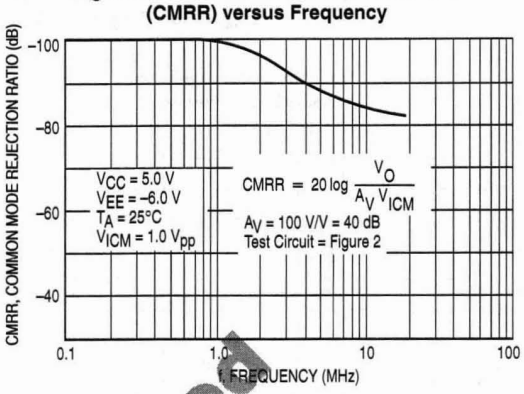



**Figure 15. Phase Shift versus Frequency**

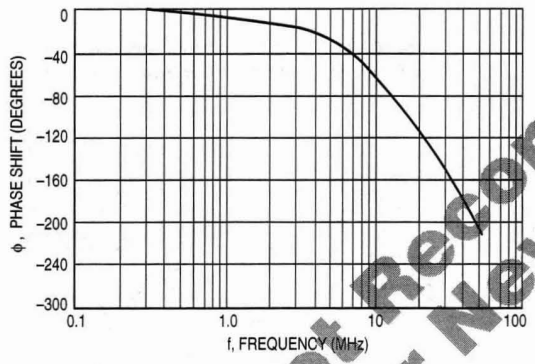
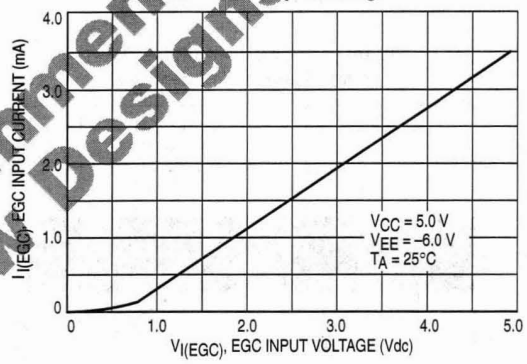


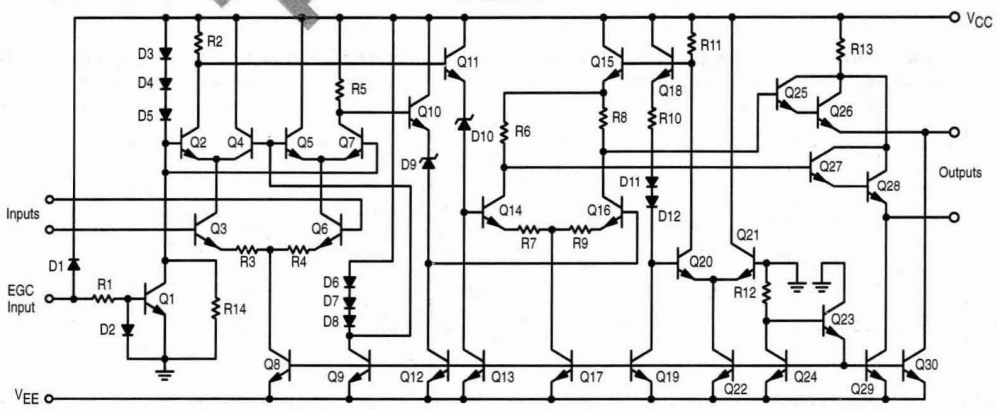

**Figure 16. Typical EGC Input Current versus EGC Input Voltage**




Not Recommended For New Designs

**Representative Schematic Diagram**

1/3 MC3467



MOTOROLA

# Quad Single-Ended Line Drivers

**MC3481**
**MC3485**

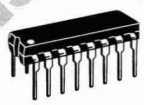
**IBM 360/370**
**QUAD LINE DRIVERS**

**SEMICONDUCTOR**
**TECHNICAL DATA**

The MC3481 and MC3485 are quad single–ended line drivers specifically designed to meet the IBM 360/370 I/O specification (GA22–6974–3).

Output levels are guaranteed over the full range of output load and fault conditions. Compliance with the IBM requirements for fault protection, flagging, and power up/power down protection for the bus make this an ideal line driver for party line operations.

- Separate Enable and Fault Flags – MC3481
- Common Enable and Fault Flag – MC3485
- Power Up/Down Does Not Disturb Bus
- Schottky Circuitry for High–Speed – PNP Inputs
- Internal Bootstraps for Faster Rise Times
- Driver Output Current Foldback Protection
- MC3485 has LS Totem Pole $\overline{\text{Driver Output}}$



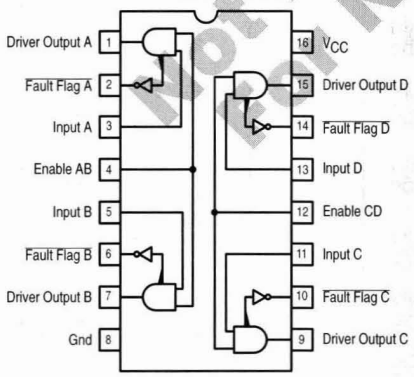
**P SUFFIX**
PLASTIC PACKAGE
CASE 648

Not Recommended For New Designs

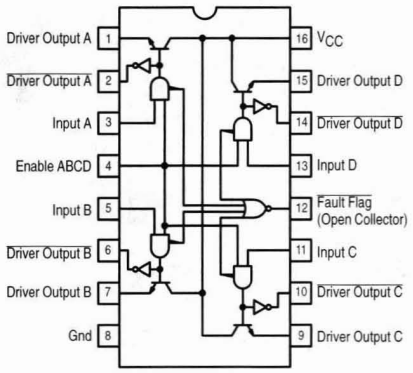
7

**PIN CONNECTIONS**

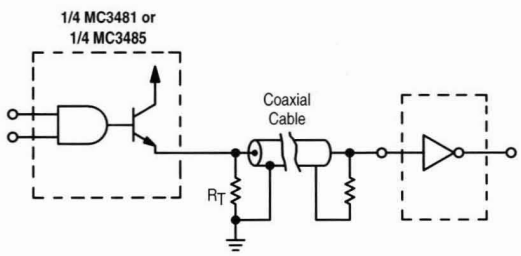
**MC3481: Dual Enable Individual Fault Flag**




**MC3485: Common Enable Common Fault Flag**




**Simplified Application**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3481P | $T_A$ = 0 to +70°C | Plastic DIP |
| MC3485P | | |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | + 7.0 | V |
| Input Voltage | $V_I$ | 10 | V |
| Driver Output Voltage | $V_O$ | 5.5 | V |
| Power Dissipation (Package Limitation)<br>Derate Above $T_A$ = 25°C | $P_D$<br>$1/R_{\theta JA}$ | 962<br>7.7 | mW<br>mW°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to + 70 | °C |
| Junction Temperature | $T_J$ | + 150 | °C |
| Storage Temperature Range | $T_{stg}$ | 65 to + 150 | °C |

**RECOMMENDED OPERATING CONDITIONS**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.5 | 5.0 | 5.95 | Vdc |
| High Level Output Current | $I_{OH}$ | – | – | 59.3 | mA |
| Operating Ambient Temperature Range | $T_A$ | 0 | – | + 70 | °C |

Not Recommended For New Designs

**SWITCHING CHARACTERISTICS** (See Note 1. Unless otherwise noted, these specifications apply over recommended temperature range. I/O Driver characteristics are guaranteed for $V_{CC}$ = 5.0 V±10 % and Select–Out Driver characteristics are guaranteed for $V_{CC}$ = 5.25 to 5.95 V. Typical values measured at $T_A$ = 25 °C and $V_{CC}$ = 5.0 V. See Tables 1 and 2, Figures 1 and 2 for load conditions.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time | | | | | ns |
| High–to–Low–Level, Driver Output | | | | | |
| As I/O Driver | $t_{PHL(D)}$ | – | 18 | – | |
| As Select–Out Driver | $t_{PHL(DS)}$ | – | 19 | – | |
| Low–to–High–Level, Driver Output | | | | | |
| As I/O Driver | $t_{PLH(\overline{D})}$ | – | 20 | – | |
| As Select–Out Driver | $t_{PLH(\overline{DS})}$ | – | 21 | – | |
| High–to–Low–Level, $\overline{\text{Driver Output}}$ | | | | | |
| As I/O Driver | $t_{PHL(\overline{D})}$ | – | 25 | – | |
| As Select–Out Driver | $t_{PHL(\overline{DS})}$ | – | 26 | – | |
| Low–to–High–Level, $\overline{\text{Driver Output}}$ | | | | | |
| As I/O Driver | $t_{PLH(\overline{D})}$ | – | 25 | – | |
| As Select–Out Driver | $t_{PLH(\overline{DS})}$ | – | 26 | – | |
| High–to–Low–Level, $\overline{\text{Fault Flag}}$ – MC3481 | | | | | |
| As I/O Driver | $t_{PHL(\overline{F})}$ | – | 45 | – | |
| As Select–Out Driver | $t_{PHL(\overline{FS})}$ | – | 47 | – | |
| Low–to–High–Level, $\overline{\text{Fault Flag}}$ – MC3481 | | | | | |
| As I/O Driver | $t_{PLH(\overline{F})}$ | – | 40 | – | |
| As Select–Out Driver | $t_{PLH(\overline{FS})}$ | – | 42 | – | |
| Ratio of Propagation Delay Times<br>As I/O Driver | $\frac{t_{PLH(D)}}{t_{PHL(D)}}$ | – | 1.0 | – | |

**NOTES:** 1. Reference IBM specification GA22–6974–3 for test terminology.
2. The fault protection circuitry of the MC3481 and MC3485 requires relatively clean input voltage waveforms for current operation. Noise pulses which enter the threshold region (0.8 to 2.0 V) may cause the output to enter the fault protect mode. To exit the protect mode, it is necessary to gate an input of the effected driver to the low logic state.

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, these specifications apply over recommended power supply and temperature ratings. Typical values measured at $T_A$ = 25°C and $V_{CC}$ = +5.0 V)

| Characteristic | Symbol | MC3481 Min | MC3481 Typ | MC3481 Max | MC3485 Min | MC3485 Typ | MC3485 Max | Unit |
|---|---|---|---|---|---|---|---|---|
| High–Level Input Voltage Note 2 | $V_{IH}$ | 2.0 | – | – | 2.0 | – | – | V |
| Low–Level Input Voltage Note 2 | $V_{IL}$ | – | – | 0.8 | – | – | 0.8 | V |
| High–Level Input Current | $I_{IH}$ | | | | | | | µA |
| ($V_{CC}$ = 4.5 V, $V_{IH}$ = 2.7 V) – Input | | – | – | 20 | – | – | 20 | |
| Enable | | – | – | 40 | – | – | 80 | |
| ($V_{CC}$ = 4.5 V, $V_{IH}$ = 5.5 V) – Input | | – | – | 100 | – | – | 100 | |
| Enable | | – | – | 200 | – | – | 400 | |
| Low–Level Input Current | $I_{IL}$ | | | | | | | µA |
| ($V_{CC}$ = 5.95 V, $V_{IL}$ = 0.4 V) – Input | | – | – | –250 | – | – | – 250 | |
| Enable | | – | – | –500 | – | – | – 1000 | |
| Input Clamp Voltage ($I_{IC}$ = –18 mA) | $V_{IC}$ | – | – | –1.5 | – | – | – 1.5 | V |
| High–Level Driver Output Voltage | | | | | | | | V |
| ($V_{CC}$ = 4.5 V, $V_{IH}$ = 2.0 V, $I_{OH}$ = – 59.3 mA) | $V_{OH(D)}$ | 3.11 | 3.6 | – | 3.11 | 3.6 | – | |
| ($V_{CC}$ = 5.25 V, $V_{IH}$ = 2.0 V, $I_{OH}$ = –41 mA) | $V_{OH(DS)}$ | 3.9 | – | – | 3.9 | – | – | |
| Low–Level Driver Output Voltage | | | | | | | | V |
| ($V_{CC}$ = 5.5 V, $V_{IL}$ = 0.8 V, $I_{OL}$ = –240 µA) | $V_{OL(D)}$ | – | – | + 0.15 | – | – | + 0.15 | |
| ($V_{CC}$ = 5.95 V, $V_{IL}$ = 0.8 V, $I_{OL}$ = –1.0 mA) | $V_{OL(DS)}$ | – | – | + 0.15 | – | – | + 0.15 | |
| Driver Output Short Circuit Current | | | | | | | | mA |
| ($V_{CC}$ = 5.5 V, $V_{IH}$ = 2.0 V, $V_{OS}$ = 0 V) | $I_{OS(D)}$ | – | – | –5.0 | – | – | – 5.0 | |
| ($V_{CC}$ = 5.95 V, $V_{IH}$ = 2.0 V, $V_{OS}$ = 0 V) | $I_{OS(DS)}$ | – | – | –5.0 | – | – | – 5.0 | |
| Driver Output Reverse Leakage Current | | | | | | | | µA |
| ($V_{CC}$ = 4.5 V, $V_{IL}$ = 0 V, $V_O$ = 3.11 V) | $I_{OR1}$ | – | – | +100 | – | – | + 100 | |
| ($V_{CC}$ = 0 V, $V_{IL}$ = 0 V, $V_O$ = 3.11 V) | $I_{OR2}$ | – | – | +200 | – | – | + 200 | |
| High–Level $\overline{\text{Driver Output}}$ Voltage ($V_{CC}$ = 4.5 V, $V_{IL}$ = 0.8 V, $I_{OH}$ = –400 µA) | $V_{OH(\overline{D})}$ | – | – | – | 2.5 | 3.0 | – | V |
| Low–Level $\overline{\text{Driver Output}}$ Voltage ($V_{CC}$ = 4.5 V, $V_{IH}$ = 2.0 V, $I_{OL}$ = 8.0 mA) | $V_{OL(\overline{D})}$ | – | – | – | – | – | 0.5 | V |
| $\overline{\text{Driver Output}}$ Short Circuit Current | | | | | | | | mA |
| ($V_{CC}$ = 5.5 V, $V_{OS}$ = 0 V, only one output shorted at a time) | $I_{OS(\overline{D})}$ | – | – | – | –15 | – 60 | –100 –110 | |
| ($V_{CC}$ = 5.95 V, $V_{OS}$ = 0 V, only one ouput shorted at a time) | $I_{OS(\overline{DS})}$ | – | – | – | –15 | – | | |
| High–Level $\overline{\text{Fault Flag}}$ Output Voltage ($V_{CC}$ = 4.5 V, $I_{OH}$ = –400 µA) | $V_{OH(\overline{F})}$ | 2 5 | 3.0 | – | – | – | – | V |
| Low–Level $\overline{\text{Fault Flag}}$ Output Voltage ($V_{CC}$ = 4.5 V, $V_{IH}$ = 2.0 V, $I_{OL}$ = 8.0 mA, Driver Output shorted to Ground | $V_{OL(\overline{F})}$ | – | – | 0.5 | – | – | 0.5 | V |
| $\overline{\text{Fault Flag}}$ Output Short Circuit Current | | | | | | | | mA |
| ($V_{CC}$ = 5.5 V, $V_{OS}$ =0 V, only one output shorted at a time) | $I_{OS(\overline{F})}$ | – 15 | – | –100 | – | – | – | |
| ($V_{CC}$ = 5.95 V, $V_{OS}$ =0 V, only one output shorted at a time) | $I_{OS(\overline{FS})}$ | – 15 | – | –110 | – | – | – | |
| High–Level $\overline{\text{Fault Flag}}$ Output Current ($V_{CC}$ = 5.95 V, $V_{OH}$ = 5.95 V) | $I_{OH(\overline{F})}$ | – | – | – | – | – | +100 | µA |
| High–Level Power Supply Current | | | | | | | | mA |
| ($V_{CC}$ = 5.5 V, $V_{IH}$ = 2.0 V, no output loading) | $I_{CCH}$ | – | 50 | 70 | – | 55 | 75 | |
| ($V_{CC}$ = 5.95 V, $V_{IH}$ = 2.0 V, no output loading) | $I_{CCHS}$ | – | – | 80 | – | – | 85 | |
| Low–Level Power Supply Current | | | | | | | | mA |
| ($V_{CC}$ = 5.5 V, $V_{IL}$ = 0.8 V, no output loading) | $I_{CCL}$ | – | 35 | 55 | – | 35 | 55 | |
| ($V_{CC}$ = 5.95 V, $V_{IL}$ = 0.8 V, no output loading) | $I_{CCLS}$ | – | – | 70 | – | – | 70 | |

Not Recommended For New Designs

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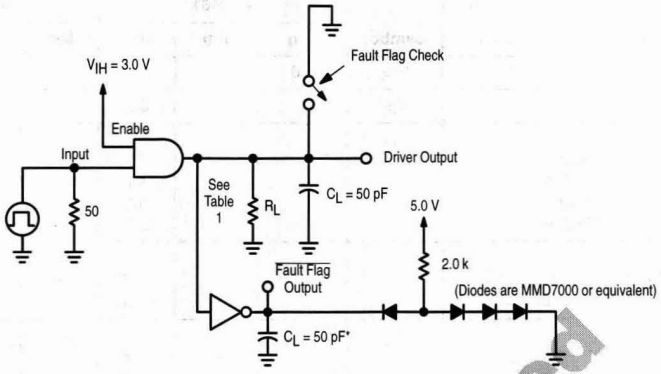
**Figure 1. MC3481 AC Test Circuit and Waveforms**




* Load Capacitance shown includes Fixture and Probe Capacitance

| Table 1 | Driver Application | |
|---|---|---|
| | I/O | Select–Out |
| $V_{OH}$ | 3.11 V | 3.9 V |
| Input Frequency | 5 MHz | 1 MHz |
| Input Pulse Width | 100 ns | 500 ns |
| Input Amplitude | 0 V to 4 V | 0 V to 4 V |
| Input $t_{TLH}$ | ≤6 ns | ≤6 ns |
| Input $t_{THL}$ | ≤6 ns | ≤6 ns |
| Load Resistance ($R_L$) | 50 | 90 |

Not Recommended For New Designs

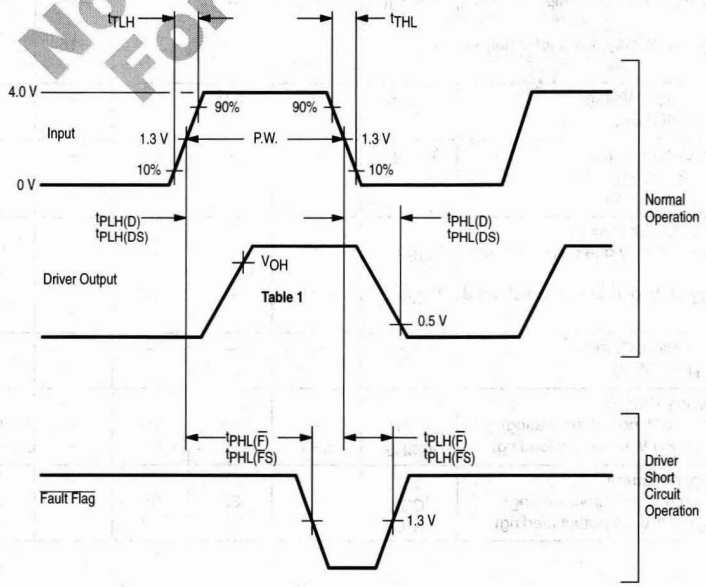
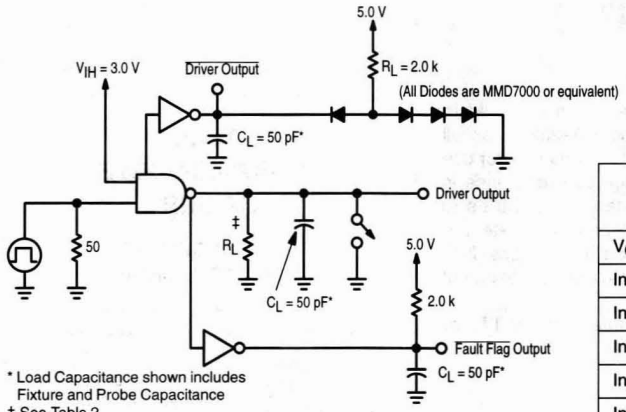
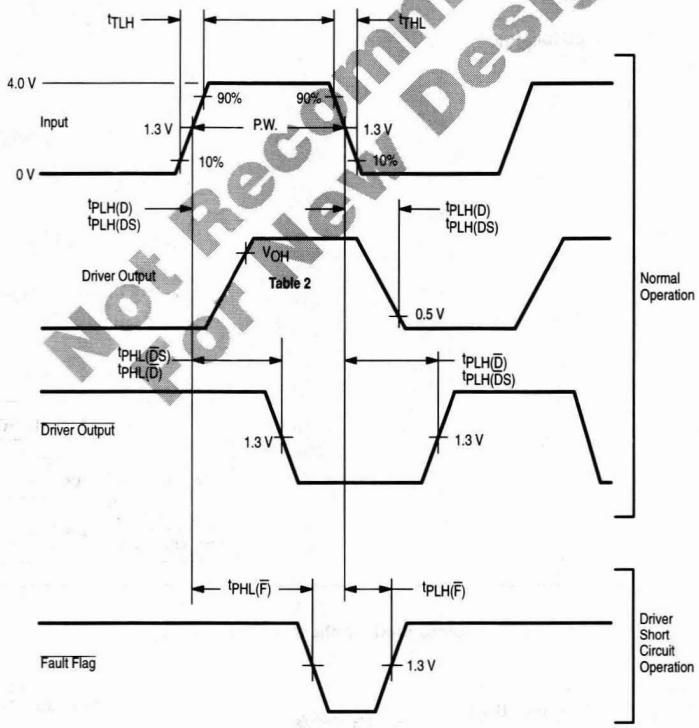


**Figure 2. MC3485 AC Test Circuit and Waveforms**




| Table 2 | Driver Application | |
|---|---|---|
| | I/O | Select–Out |
| $V_{OH}$ | 3.11 V | 3.9 V |
| Input Frequency | 5 MHz | 1 MHz |
| Input Pulse Width | 100 ns | 500 ns |
| Input Amplitude | 0 V to 4 V | 0 V to 4 V |
| Input $t_{TLH}$ | ≤6 ns | ≤6 ns |
| Input $t_{THL}$ | ≤6 ns | ≤6 ns |
| Load Resistance ($R_L$) | 50 | 90 |




Not Recommended For New Designs

7

MOTOROLA

# MC3488A

# Dual EIA-423/EIA-232D Line Driver

**DUAL**
**EIA–423/EIA–232D**
**DRIVER**

**SEMICONDUCTOR**
**TECHNICAL DATA**

The MC3488A dual is single–ended line driver has been designed to satisfy the requirements of EIA standards EIA–423 and EIA–232D, as well as CCITT X.26, X.28 and Federal Standard FIDS1030. It is suitable for use where signal wave shaping is desired and the output load resistance is greater than 450 ohms. Output slew rates are adjustable from 1.0 µs to 100 µs by a single external resistor. Output level and slew rate are insensitive to power supply variations. Input undershoot diodes limit transients below ground and output current limiting is provided in both output states.

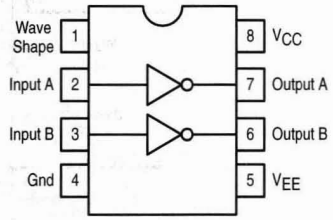
The MC3488A has a standard 1.5 V input logic threshold for TTL or NMOS compatibility.

- PNP Buffered Inputs to Minimize Input Loading
- Short Circuit Protection
- Adjustable Slew Rate Limiting
- MC3488A Equivalent to 9636A
- Output Levels and Slew Rates are Insensitive to Power Supply Voltages
- No External Blocking Diode Required for $V_{EE}$ Supply
- Second Source µA9636A

**P1 SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

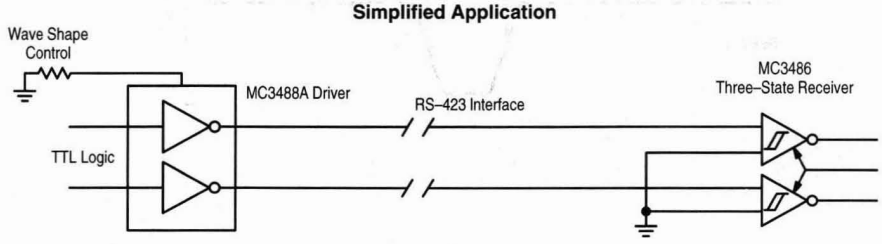
**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3488AP1 | $T_A$ = 0 to +70°C | Plastic DIP |
| MC3488AD | | SO–8 |

**Simplified Application**



**MAXIMUM RATINGS** (Note 1)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltages | $V_{CC}$<br>$V_{EE}$ | + 15<br>– 15 | V |
| Output Current<br>Source<br>Sink | <br>$I_{O+}$<br>$I_{O-}$ | <br>+ 150<br>– 150 | mA |
| Operating Ambient Temperature | $T_A$ | 0 to + 70 | °C |
| Junction Temperature Range | $T_J$ | 150 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 150 | °C |

**RECOMMENDED OPERATING CONDITIONS**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltages | $V_{CC}$<br>$V_{EE}$ | 10.8<br>– 13.2 | 12<br>– 12 | 13.2<br>– 10.8 | V |
| Operating Temperature Range | $T_A$ | 0 | 25 | 70 | °C |
| Wave Shaping Resistor | $R_{WS}$ | 10 | – | 1000 | kΩ |

**TARGET ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, specifications apply over recommended operating conditions)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Voltage – Low Logic State | $V_{IL}$ | – | – | 0.8 | V |
| Input Voltage – High Logic State | $V_{IH}$ | 2.0 | – | – | V |
| Input Current – Low Logic State<br>($V_{IL}$ = 0.4 V) | $I_{IL}$ | – 80 | – | – | µA |
| Input Current – High Logic State<br>($V_{IH}$ = 2.4 V)<br>($V_{IH}$ = 5.5 V) | <br>$I_{IH1}$<br>$I_{IH2}$ | <br>–<br>– | <br>–<br>– | <br>10<br>100 | µA |
| Input Clamp Diode Voltage<br>($I_{IK}$ = – 15 mA) | $V_{IK}$ | – 1.5 | – | – | V |
| Output Voltage – Low Logic State<br>($R_L$ = ∞) EIA–423<br>($R_L$ = 3.0 kΩ) EIA–232D<br>($R_L$ = 450 Ω) EIA–423 | $V_{OL}$ | <br>– 6.0<br>– 6.0<br>– 6.0 | <br>–<br>–<br>– | <br>– 5.0<br>– 5.0<br>– 4.0 | V |
| Output Voltage – High Logic State<br>($R_L$ = ∞) EIA–423<br>($R_L$ = 3.0 kΩ) EIA–232D<br>($R_L$ = 450 Ω) EIA–423 | $V_{OH}$ | <br>5.0<br>5.0<br>4.0 | <br>–<br>–<br>– | <br>6.0<br>6.0<br>6.0 | V |
| Output Resistance<br>($R_L \geq$ 450 Ω) | $R_O$ | – | 25 | 50 | Ω |
| Output Short–Circuit Current (Note 2)<br>($V_{in}$ = $V_{out}$ = 0 V)<br>($V_{in}$ = $V_{IH(Min)}$, $V_{out}$ = 0 V) | <br>$I_{OSH}$<br>$I_{OSL}$ | <br>– 150<br>+ 15 | <br>–<br>– | <br>– 15<br>+ 150 | mA |
| Output Leakage Current (Note 3)<br>($V_{CC}$ = $V_{EE}$ = 0 V, – 6.0 V ≤ $V_o$ ≤ 6.0 V) | $I_{ox}$ | – 100 | – | 100 | µA |
| Power Supply Currents<br>($R_W$ = 100 kΩ, $R_L$ = ∞, $V_{IL}$ ≤ $V_{in}$ ≤ $V_{IH}$) | $I_{CC}$<br>$I_{EE}$ | –<br>– 18 | –<br>– | + 18<br>– | mA |

**NOTES:** 1. Devices should not be operated at these values. The "Electrical Characteristics" provide conditions for actual device operation.
2. One output shorted at a time.
3. No $V_{EE}$ diode required.

**TRANSITION TIMES** (Unless otherwise noted, $C_L$ = 30 pF, f = 1.0 kHz, $V_{CC}$ = – $V_{EE}$ = 12.0 V ± 10%, $T_A$ = 25°C, $R_L$ = 450 Ω. Transition times measured 10% to 90% and 90% to 10%)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Transition Time, Low–to–High State Output | $t_{TLH}$ | | | | µs |
| ($R_W$ = 10 kΩ) | | 0.8 | – | 1.4 | |
| ($R_W$ = 100 kΩ) | | 8.0 | – | 14 | |
| ($R_W$ = 500 kΩ) | | 40 | – | 70 | |
| ($R_W$ = 1000 kΩ) | | 80 | – | 140 | |
| Transition Time, High–to–Low State Output | $t_{THL}$ | | | | µs |
| ($R_W$ = 10 kΩ) | | 0.8 | – | 1.4 | |
| ($R_W$ = 100 kΩ) | | 8.0 | – | 14 | |
| ($R_W$ = 500 kΩ) | | 40 | – | 70 | |
| ($R_W$ = 1000 kΩ) | | 80 | – | 140 | |

**Figure 1. Test Circuit and Waveforms for Transition Times**

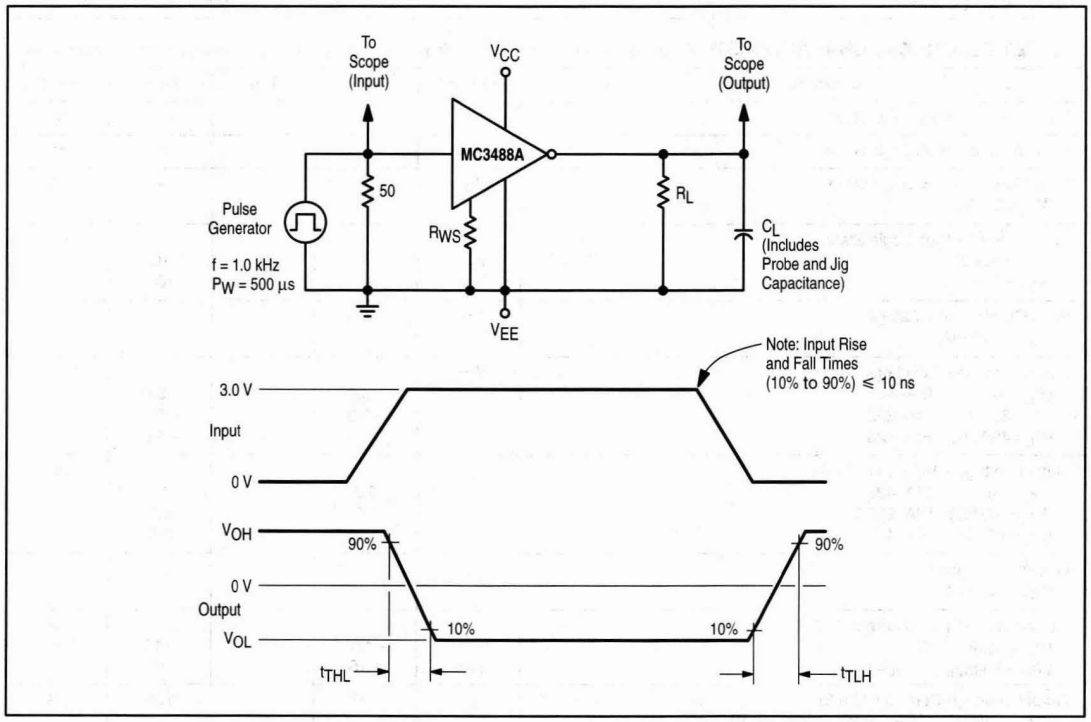


**Figure 2. Output Transition Times versus Wave Shape Resistor Value**

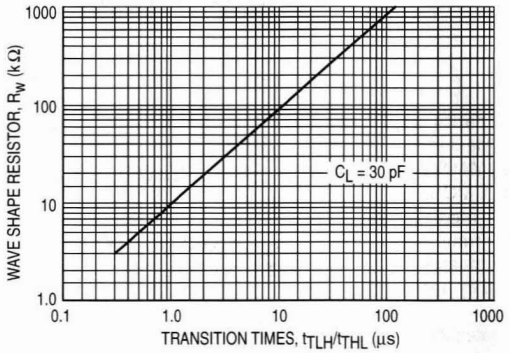



**Figure 3. Input/Output Characteristics versus Temperature**

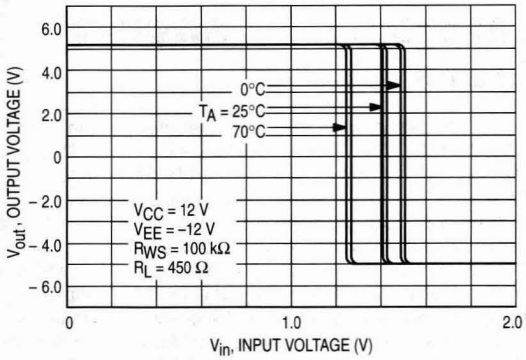
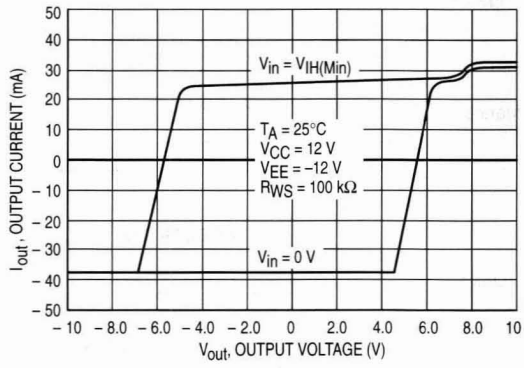



**Figure 4. Output Current versus Output Voltage**

**Power–On**




**Power–Off**

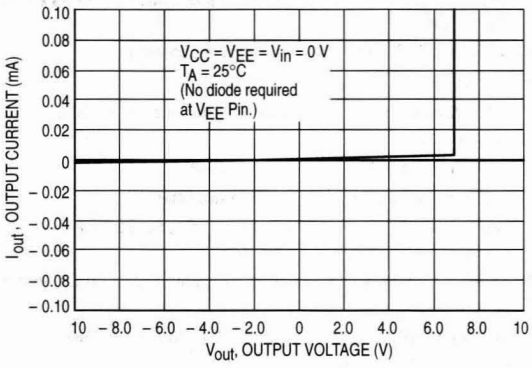



**Figure 5. Supply Current versus Temperature**

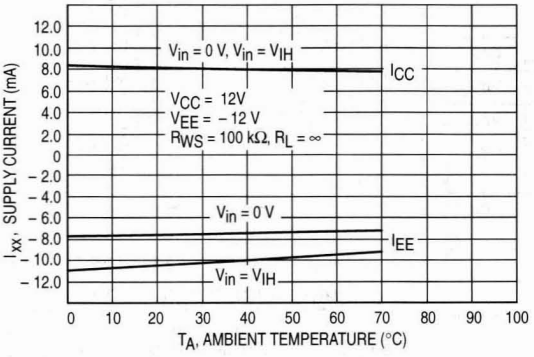
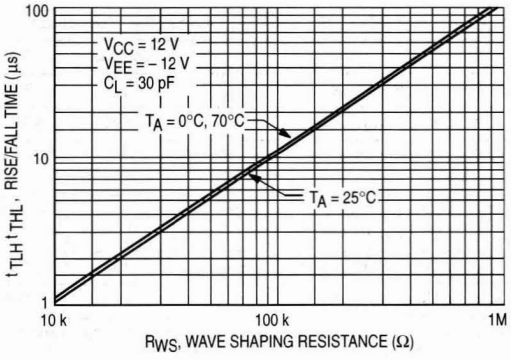



**Figure 6. Rise/Fall Time versus $R_{WS}$**

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MOTOROLA

# MC34055

# IEEE 802.3 10BASE-T Transceiver

**10BASE–T TRANSCEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

The Motorola 10BASE–T transceiver, designed to comply with the ISO 8802–3 [IEEE 802.3] 10BASE–T specification, will support a Medium Dependent Interface (MDI) in an embedded Media Attachment Unit (MAU)*. The interface supporting the Data Terminal Equipment (DTE) is TTL, CMOS, and raised ECL compatible, and the interface to the Twisted Pair (TP) media is supported through standard 10BASE–T filters and transformers. Differential data intended for the TP media is provided a 50 ns pre–emphasis and data at the TP receiver is screened by Smart Squelch circuitry for specific threshold, pulse width, and sequence requirements.

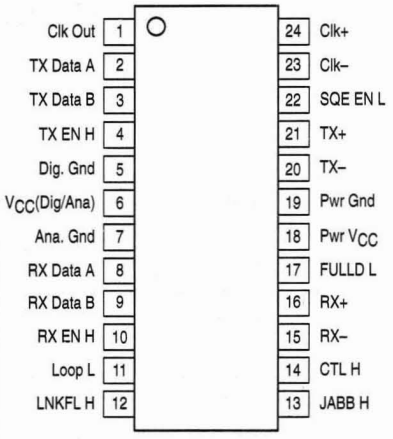
Other features of the MC34055 include: Collision and Jabber detection status outputs, select mode pins for forcing Loop Back and Full–Duplex operation, a Signal Quality Error pin for testing the collision detect circuitry without affecting the TP output, and a LED driver for Link Integrity status. An on–chip oscillator, capable of receiving a clock input or operating under crystal control, is also provided for internal timing and driving a buffered clock output.

The MC34055 is manufactured on a BiCMOS process and is packaged in a 24 pin SOIC.

- BiCMOS Technology for Low Power Operation
- Standard 5.0 V, ± 5% Voltage Supply
- Smart Squelch Enforcement of Threshold, Pulse Width, and Sequence Requirements
- Driver Pre–Emphasis for Output Data
- TTL, CMOS and Raised ECL Compatible
- Interfaces to TP Media with Standard 10BASE–T Filters and Transformers
- LED Capable Status Outputs for Collision, Jabber Detection, and Link Integrity
- Directly Driven or Crystal Controlled Clock Oscillator
- Selectable Full–Duplex Operation
- Signal Quality Error Test Pin
- Selectable Loop Back

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
(SO–24L)

**PIN CONNECTIONS**




**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

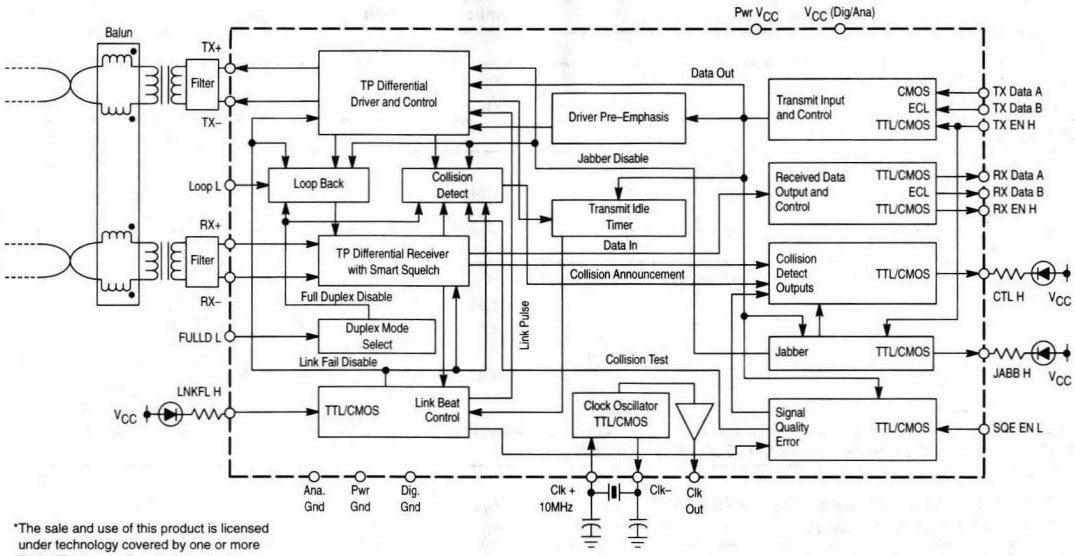
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | – 0.5 to 7.0 | Vdc |
| Differential Voltage at RX+/RX– | $V_{ID}$ | – 5.25 to 5.25 | Vdc |
| Voltage Applied to Logic and Mode/Test Select Inputs | | – 0.5 to 5.5 | Vdc |
| Voltage Applied to Logic Outputs and Output Status Pins | | – 0.5 to 7.0 | Vdc |
| Ambient Operating Temperature Range | $T_A$ | 0 to 70 | °C |
| Junction Temperature | $T_J$ | – 65 to 150 | °C |

**NOTE:** Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides for actual device operation.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC34055DW | $T_A$ = 0° to +70°C | SO–24L |

## Simplified Block Diagram




*The sale and use of this product is licensed under technology covered by one or more Digital Equipment Corporation patents.

This device contains 9,875 active transistors.

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### RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.75 | 5.0 | 5.25 | Vdc |
| Voltage Applied to Logic Inputs and Status Pins | – | 0 | – | 5.25 | Vdc |
| Differential Input Voltage | – | 0.59 | – | 2.8 | Vpp |
| Operating Ambient Temperature | $T_A$ | 0 | – | 70 | °C |

**NOTE:** All limits are not necessarily functional concurrently.

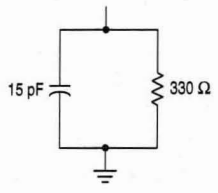
### ELECTRICAL CHARACTERISTICS ($0°C \le T_A \le 70°C$, $V_{CC}$ = 5.0 V, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current (4.75 V ≤ $V_{CC}$ ≤ 5.25 V) | $I_{CC}$ | – | 60 | 180 | mA |
| Reset Circuit Threshold | – | 4.0 | – | 4.4 | Vdc |
| **TWISTED PAIR TRANSMITTER** | | | | | |
| Output Differential Voltage (See Load Circuits: Differential Load Circuit) | $V_O$ | | | | Vpp |
| Output Differential Voltage with Pre–Emphasis | | 2.2 | 2.53 | 2.8 | |
| Output Differential Voltage | | 1.56 | 1.72 | 1.98 | |
| Common Mode Driver Impedance | $Z_{OCM}$ | 6.0 | 8.5 | 14 | Ω |
| Transmitter Differential Output Impedance | $Z_{OD}$ | 8.0 | 15.5 | 29 | Ω |
| **TX DATA A** | | | | | |
| Input High Voltage ($I_{IH}$ = + 20 μA) | $V_{IH}$ | 3.15 | – | 5.25 | Vdc |
| Input Low Voltage ($I_{IL}$ = –150 μA) | $V_{IL}$ | 0 | – | 0.8 | |
| **TX DATA B** | | | | | |
| Input Voltage (See Load Circuits: ECL Load Circuit) | | | | | Vdc |
| High: @ 0°C | $V_{IH}$ | 0.984 $V_{CC}$ – 0.923 | | 0.984 $V_{CC}$ – 0.763 | |
| @ 25°C | | 0.984 $V_{CC}$ – 0.877 | | 0.984 $V_{CC}$ – 0.727 | |
| @ 70°C | | 0.984 $V_{CC}$ – 0.825 | | 0.984 $V_{CC}$ – 0.644 | |
| Low: @ 0°C | $V_{IL}$ | 0.750 $V_{CC}$ – 0.568 | | 0.750 $V_{CC}$ – 0.361 | |
| @ 25°C | | 0.750 $V_{CC}$ – 0.550 | | 0.750 $V_{CC}$ – 0.350 | |
| @ 70°C | | 0.750 $V_{CC}$ – 0.531 | | 0.750 $V_{CC}$ – 0.324 | |

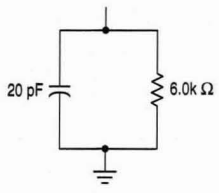
**ELECTRICAL CHARACTERISTICS** ($0°C \le T_A \le 70°C$, $V_{CC}$ = 5.0 V, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **TX EN H** | | | | | |
| Input High Voltage ($I_{IH}$ = 200 µA) | $V_{IH}$ | 2.0 | – | 5.0 | Vdc |
| Input Low Voltage ($I_{IL}$ = – 20 µA) | $V_{IL}$ | 0 | – | 0.8 | |
| **RX DATA A/RX EN H/JABB H/CTL H** | | | | | |
| Output Voltage (See Load Circuits: CMOS Load Circuit) | | | | | Vdc |
| High ($I_{OH}$ = –12 mA) | $V_{OH}$ | 3.7 | – | – | |
| Low ($I_{OL}$ = +16 mA) | $V_{OL}$ | – | – | 0.5 | |
| **RX DATA B** | | | | | |
| Output Voltage (See Load Circuits: ECL Load Circuit) | | | | | Vdc |
| High: @ 0°C | $V_{OH}$ | 0.984 $V_{CC}$ – 0.923 | | 0.984 $V_{CC}$ – 0.763 | |
| @ 25°C | | 0.984 $V_{CC}$ – 0.877 | | 0.984 $V_{CC}$ – 0.727 | |
| @ 70°C | | 0.984 $V_{CC}$ – 0.825 | | 0.984 $V_{CC}$ – 0.644 | |
| Low: @ 0°C | $V_{OL}$ | 0.750 $V_{CC}$ – 0.568 | | 0.750 $V_{CC}$ – 0.361 | |
| @ 25°C | | 0.750 $V_{CC}$ – 0.550 | | 0.750 $V_{CC}$ – 0.350 | |
| @ 70°C | | 0.750 $V_{CC}$ – 0.531 | | 0.750 $V_{CC}$ – 0.324 | |
| **SIGNAL QUALITY ERROR TEST ENABLE CONTROL (SQE EN L)** | | | | | |
| Test Control Voltage | | | | | Vdc |
| Test Disabled (Input High Voltage)($I_{IH}$ = + 20 µA Max.) | $V_{IH}$ | 2.0 | – | 5.0 | |
| Test Enabled (Input Low Voltage)(– 50 µA < $I_{IL}$ < –150 µA) | $V_{IL}$ | 0 | – | 0.8 | |
| **FULL DUPLEX MODE SELECT (FULLD L)** | | | | | |
| Mode Select Control Voltage | | | | | Vdc |
| Normal Operation (Input High)($I_{IH}$ = + 20 µA) | $V_{IH}$ | 2.0 | – | 5.0 | |
| Full Duplex (Input Low)(– 50 µA < $I_{IH}$ < –150 µA) | $V_{IL}$ | 0 | – | 0.8 | |
| **LOOPBACK TEST MODE FUNCTION (LOOP L)** | | | | | |
| Test Control Voltage | | | | | Vdc |
| Test Disabled (Input High)($I_{IH}$ = + 20 µA) | $V_{IH}$ | 2.0 | – | 5.0 | |
| Test Enabled (Input Low)($I_{IL}$ = – 200 µA) | $V_{IL}$ | 0 | – | 0.8 | |
| **LINK FAIL STATUS (LINKFL H)** | | | | | |
| Status Output Voltage (See Load Circuits: CMOS Load Circuit) | | | | | |
| Maximum Voltage for Output Low Condition ($I_{OL}$ = 20 mA) | $V_{OH}$ | – | – | 0.5 | Vdc |
| Output Low Sink Current | $V_{OL}$ | – | – | 20 | mA |
| **CLOCK OSCILLATOR** | | | | | |
| Clk+ Input Logic Threshold | | | | | |
| High Level Input Voltage ($I_{IH}$ = +100 µA Max.) | $V_{IH}$ | 2.0 | – | 5.0 | Vdc |
| Logic Low Input Voltage ($I_{IL}$ = –100 µA Max.) | $V_{IL}$ | – | – | 0.8 | µA |
| Clk Out Output Voltage (See Load Circuits: CMOS Load Circuit) | | | | | Vdc |
| Logic High ($I_{OH}$ = –12 mA) | $V_{OH}$ | 3.7 | 3.9 | – | |
| Logic Low ($I_{out}$ = +16 µA) | $V_{OL}$ | – | 0.25 | 0.5 | |

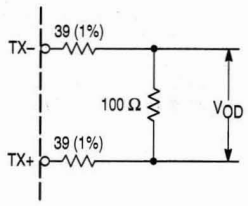
**Output Load Circuits**




ECL Load Circuit




TTL/CMOS Load Circuit




Differential Load Circuit

**TIMING CHARACTERISTICS** ($0°C \le T_A \le 70°C$)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **TRANSMIT START TIMING** | | | | | |
| TX EN H to TX+/TX– Enable Time | $t_{TXEN}$ | – | – | 75 | ns |
| TX Data A/B to TX+/TX– Enable Time | $t_{FDXD}$ | – | – | 75 | ns |
| Steady State Propagation Delay of TX Data A/B to TX+/TX– Output | $t_{TXSS}$ | – | – | 75 | ns |
| Pre–Emphasis Pulse Width | $t_{PRCM}$ | 45 | – | 55 | ns |
| Transmitter Caused Edge Skew Between TX+ and TX– | $t_{Skew\ T}$ | – | – | 2.0 | ns |
| Transmitter Added Edge Jitter to TX+/TX– from TX Data A/B | $t_{Jitter\ T}$ | – | – | 4.0 | ns |
| Steady–State Delay between the TX Data A/B Input to the RX Data A/B Outputs for Normal Operation | $t_{TXRX}$ | – | – | 50 | ns |
| TX EN H Assert to RX EN H Assert Under Normal Operation | $t_{DREL}$ | – | – | 50 | ns |
| **TRANSMIT STOP TIMING** | | | | | |
| Delay between TX EN H Low and TX+/TX– High | $t_{TXDH}$ | – | – | 75 | ns |
| TX EN H Assert/De–assert Delay from TX EN H to RX EN H Assert/De–assert | $t_{XTRE}$ | – | – | 400 | ns |
| End of Packet Hold Time from Last TX Data A/B Edge or TX EN H De–assert | $t_{TDDC}$ | 250 | – | – | ns |
| **LINK BEAT PULSES** | | | | | |
| Output Link Test Pulse Width | $t_{LKPW}$ | 80 | – | 120 | ns |
| Minimum Link Beat Pulse Duration on RX+/RX– | $t_{LDCY\_A}$ | 80 | – | 192 | ns |
| **LOOP BACK MODE TIMING** | | | | | |
| Delay from Loop L Deassertion to RX EN H Driven from TX EN H Status | $t_{LTRA}$ | – | – | 30 | ns |
| TX EN H Assert/De–assert to RX EN H, Assert/De–assert when in Loop–Back Mode and Receiver Inactive | $t_{LTRX}$ | – | – | 50 | ns |
| Steady–State TX Data A/B to RX Data A/B when in Loop–Back Mode | $t_{LTRD}$ | – | – | 50 | ns |
| **SMART SQUELCH** | | | | | |
| Interval Unit Squelch Deactivation | $t_{SQ}$ | – | – | 5.0 | Bit Times |
| **RECEIVE START TIMING** | | | | | |
| Receiver–Added Edge Skew to RX Data A/B Signal | $t_{Skew\ R}$ | – | – | 1.5 | ns |
| Receiver–Added Edge Jitter to RX Data A/B Signal | $t_{Jitter\ R}$ | – | – | 1.5 | ns |
| Start–Up Delay from RX+/RX– to RX Data A/B | $t_{RXNE}$ | – | – | 50 | ns |
| Delay from RX EN H Assertion Until RX Data A/B Valid | $t_{RARE}$ | –10 | – | +10 | ns |
| Steady–State Propagation Delay from RX+/RX– Data A/B | $t_{RXSS}$ | – | – | 50 | ns |
| **RECEIVE SHUTDOWN TIMING** | | | | | |
| Last received Data Edge until the RX EN H Output forces low | $t_{RXDE}$ | 155 | – | 250 | ns |

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**Figure 1. Start Up and Steady State Transmit Timing**

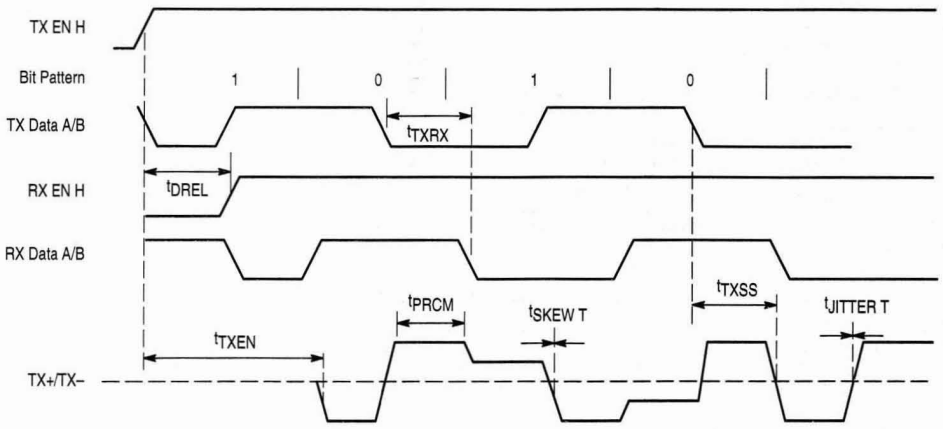


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**Figure 2. Driver Shutdown Timing**

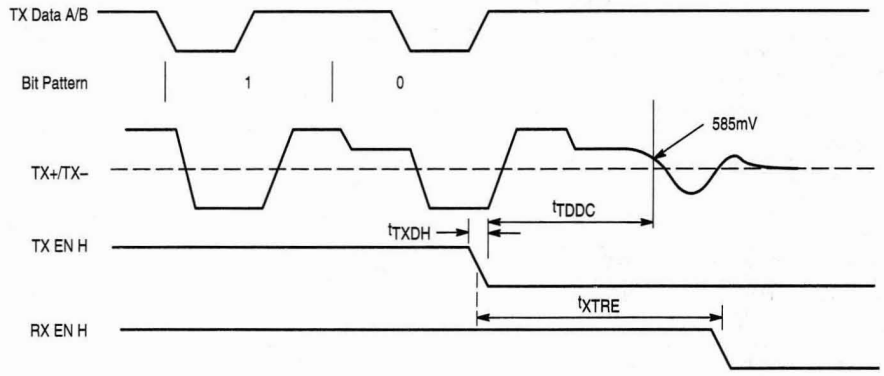



**Figure 3. Link Pulse Timing**

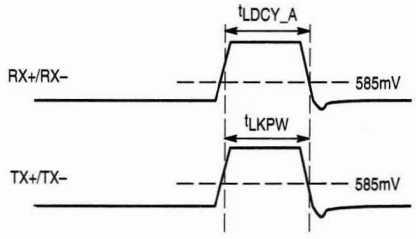


**Figure 4. Loop Back Timing**

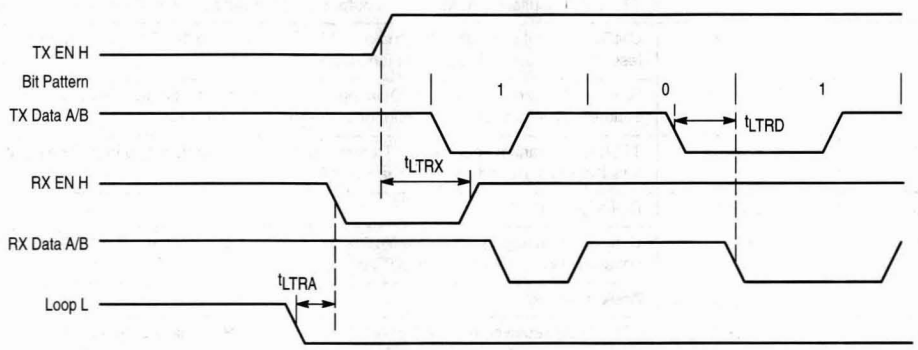



**Figure 5. Receive Startup Timing**

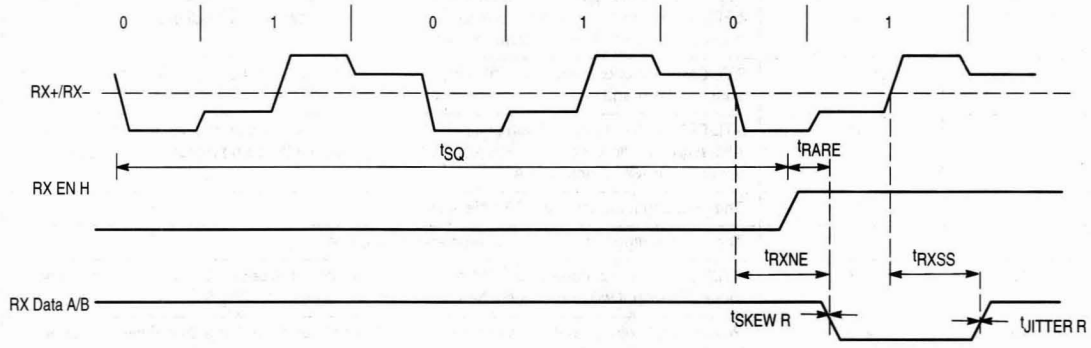
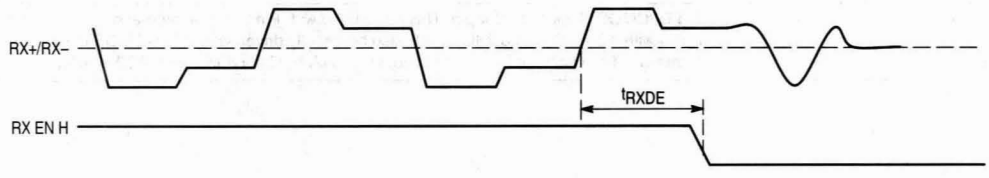



**Figure 6. Receive Shutdown Timing**



## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Description |
|---|---|---|
| 1 | Clk Out | TTL/CMOS buffered 10 MHz clock output. This pin will source 400 μA and sink 16 mA. |
| 2 | TX Data A | CMOS transmit input pin. Data input at this pin is output to the TP media. The input will source less than 175 μA and sink less than 20 μA. |
| 3 | TX Data B | Raised ECL transmit input pin. Data input at this pin is output to the TP media. The input can source 40 μA for a high level input or 70 μA for a low level input. |
| 4 | TX EN H | TTL/CMOS transmit enable pin. Transmit is enabled when asserted high. The input will source less than 175 μA and sink less than 20 μA. |
| 5 | Dig. Gnd | Digital ground |
| 6 | $V_{CC}$(Dig/Ana) | Digital and analog $V_{CC}$. With the current consumed at this pin and Pin 18, the device will consume less than 180 mA at 5.0 Vdc. |
| 7 | Ana. Gnd | Analog ground |
| 8 | RX Data A | TTL/CMOS received data output pin. Data from the TP media is output at this pin. The output will source 12 mA and sink 16 mA. |
| 9 | RX Data B | Raised ECL received data output pin. Data from the TP media is output at this pin. |
| 10 | RX EN H | TTL/CMOS received data output enable pin. This pin is asserted after the Smart Squelch circuitry determines that there is valid data at the TP input pins and also when internal loop–back is occurring. The output will source 12 mA and sink 16 mA. The receive data outputs are forced high when this pin is low. |
| 11 | Loop L | TTL/CMOS Loopback test select. Asserting this pin causes the transmit data to be looped to the receive circuit while the TP transmit driver sends a link pulse. The input will source less than 175 μA and sink less than 20 μA. |
| 12 | LNKFL H | This pin is driven high to indicate a link fail state. When low, the pin will sink 20 mA to light an LED. An usquelched condition due to valid data on the receive circuit will cause the pin to transition high and low in 100 ms intervals. |
| 13 | JABB H | TTL/CMOS Jabber status pin. This pin is asserted when a Jabber condition is detected and will source 12 mA and sink 16 mA. |
| 14 | CTL H | TTL/CMOS status pin. This pin pulled high when Jabber or Collision conditions are detected. Also high for a time interval when a Signal Quality Error test is being performed. The pin will source 12 mA and sink 16 mA. |
| 15 | RX– | The inverting terminal of the TP differential receiver. |
| 16 | RX+ | The noninverting terminal of the TP differential receiver. |
| 17 | FULLD L | TTL/CMOS duplex mode select. When low, this pin forces the device to operate in full–duplex mode. The input will source less than 175 μA and sink less than 20 μA. |
| 18 | Pwr $V_{CC}$ | Power supply pin. With the current consumed at this pin and Pin 6, the device will consume less than 180 mA at 5.0 Vdc. |
| 19 | Pwr Gnd | Power ground pin. |
| 20 | TX– | The inverting terminal of the TP differential driver. |
| 21 | TX+ | The noninverting terminal of the TP differential driver. |
| 22 | SQE EN L | TTL/CMOS Signal Quality Error test enable pin. Pulling this pin low allows test of the collision detect circuitry without affecting the twisted pair channel. The input will source less than 175 μA and sink less than 20 μA. |
| 23 | Clk– | TTL/CMOS clock oscillator pin. See Pin 24. |
| 24 | Clk+ | TTL/CMOS clock oscillator pin. This pin is used with Pin 23 if the internal oscillator is to be free run with a crystal. The oscillator can also be directly driven with a TTL/CMOS clock signal at this pin. The oscillator frequency should be 10 MHz with a duty cycle of 50 ± 20%. |

## FUNCTIONAL DESCRIPTION

### Introduction

The Motorola 10BASE–T transceiver, designed to comply with the ISO 8802–3[IEEE 802.3] 10BASE–T specification, will support one Medium Dependent Interface (MDI) through standard 10BASE–T filters and transformers. Although the device is capable of being used in embedded or external Medium Attachment Units (MAU), it was primarily designed for use in repeater or hub applications. For this reason a digital interface is provided rather than an AUI interface. This interface is TTL, CMOS, and raised ECL compatible and allows for easy connection in hub applications.

Other features of the MC34055 include: select mode pins of forcing Loop–Back and Full–Duplex operation; a Signal Quality Error pin for testing the collision detect circuitry without affecting the twisted pair output; and LED drivers for Link Integrity status; Collision detection; and Jabber detection. An on chip oscillator, capable of receiving a clock input or operating under crystal control, is also provided for internal timing and driving a buffered clock output.

### Data Transmission

For data intended for the twisted pair, the MC34055 has two data inputs, TX Data A and TX Data B. TX Data A is CMOS compatible and TX Data B is raised ECL compatible. The inputs were not intended to be used simultaneously in a single application and are internally logically combined. The unused input should be disabled by connection to $V_{CC}$.

When data transmission is intended, the MC34055 detects the first falling edge of the Manchester encoded frame at the input being used, synchronizes the on chip oscillator (Pins 23 and 24) and asserts the twisted pair driver output to full differential amplitude within 25 ns if the driver enable pin (TX EN H) is previously asserted. Also, since twisted pair attenuates a 10 MHz signal more than a 5.0 MHz signal the 10BASE–T standard requires that data applied to the twisted pair receive pre–equalization. To fulfill this requirement the MC34055 provides an additional 730 mV for approximately 50 ns to output data. This is accomplished over the single pair of differential driver pins. TX+ and TX–, and effectively equalizes the power of all data components at the receiver. Figure 7A shows a 10 MHz waveform. Figure 7B shows the effect of pre–emphasis on a 5.0 MHz waveform. Manchester encoded data with the pattern shown in Figure 7A would represent a repeating pattern of zeros (000000...). Figure 7B would represent an alternating pattern of ones and zeros (0101010...).

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**Figure 7A. 10 MHz Waveform on Differential Outputs**

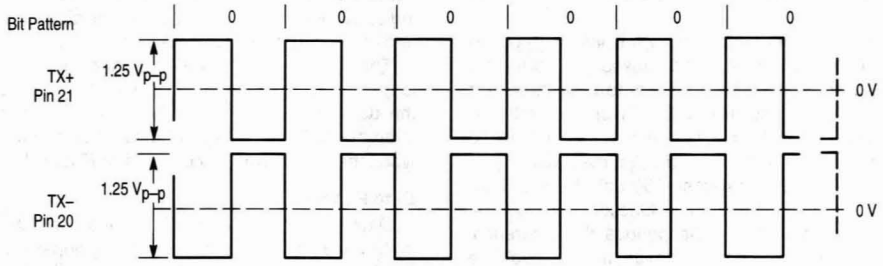
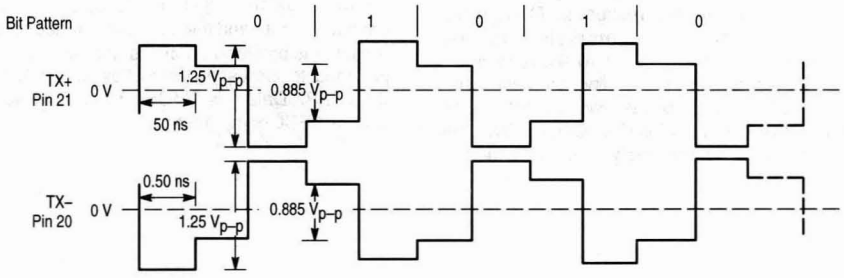



**Figure 7B. 5.0 MHz Waveform on Differential Outputs**

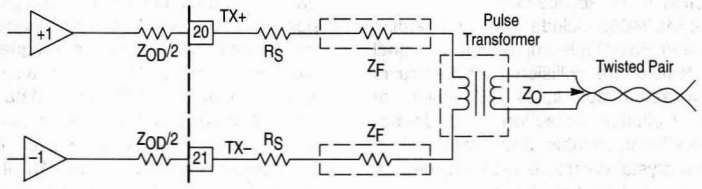


The figures show the voltage waveforms on the differential driver output pins. To actually meet the 10BASE–T specification requires bandpass filtering and a pulse transformer.

The output voltage waveform specifications of the IEEE 802.3 standard require that voltages impressed on the twisted pair meet a voltage template. The MC34055 can meet the voltage template for all the 10BASE–T applications initiated. In this event, the transmit differential driver will remain active for the entire frame interval and the link pulse will not affect more than one bit interval.

The MC34055 also has Jabber circuitry to detect and disable the twisted pair driver in the event that a serial controller fails constantly transmitting. Should any data source try to transmit longer than 20 ms minimum, the Jabber function will disable the differential driver outputs, the

**Figure 8. Differential Driver Media Interface Circuitry**




Where: $Z_{OD}$ is the transmitters differential output impedance (~20 Ω),
$R_S$ is a 1% series resistor,
$Z_F$ is the filters impedance, and $Z_O$ is the characteristic impedance of the twisted pair (100 Ω).

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by choosing the appropriate low pass filter and external components in the driver output circuitry. When the differential transmit driver output pins are configured to drive the bandpass filters and pulse transformer as shown in Figure 8, the resultant waveform is capable of meeting the voltage template.

Following the end–of–frame activity, an internal pull–up resistor pulls TX Data A/B high and causes the differential driver to maintain full differential output voltage for approximately 250 ns. The differential driver interprets the lack of transition activity as an end of frame and starts an idle timer. Should another frame intended for the twisted pair arrive before the idle timer expires(~250 ns), the idle timer will be reset, if not, the transmit driver function will begin the decay to idle process. During idle periods the differential driver must force the media to a minimal differential voltage unless a link beat is being produced. The transition to minimal voltage is subject to performance requirements in the IEEE specification and is met by the MC34055 when the appropriate filters and transformers are used to interface to the media.

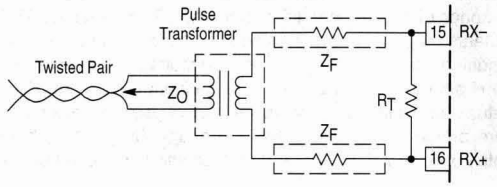
The MC34055 differential driver generates link pulses (beats) during idle periods. The link pulses produced are singular positive (TX+ positive with respect to TX–) pulses applied to the media at 16 ms intervals and last approximately 100 ns. The link pulses allow the receiver at the other end of the link to verify the validity of the segment. There is the possibility, due to the two asynchronous sources, that one of the two input pins (TX Data A or TX Data B) will receive frame activity immediately after a link pulse is collision presence detector and the internal loopback function. Also, two status indicator pins, CTL H and JABB H are asserted. The MC34055 will remain in the jabber state until the TX EN H pin is pulled low or the jabbering input ceases to toggle for a minimum of 500 ms. The status indicator pins, CTL H and JABB H will also sink up to 20 mA and can therefore support external LEDs.

The driver also works with the receiver to provide loop–back. Under normal operating conditions (Loop L= "1"), the data applied to the TX Data A/B pins is looped back internally to the RX Data A/B pins. This function is disabled when there is a collision condition or FULLD L is low.

### Data Reception

Data intended for the DTE proceeds from the twisted pair to the isolation transformer and bandpass filters before reaching the differential receiver terminals. Figure 9 shows the configuration of the external media receive circuitry. Once transitions at the receiver terminals (RX+ and RX–) are detected, the on–chip oscillator is synchronized and the received data is screened by smart squelch circuitry for validity. This qualification requires incoming data to meet amplitude and sequence requirements. If the data meets the Smart Squelch requirements, the receiver enters the unsquelch state and the data is forwarded to the RX Data A/B output pins provided Loop L is not low. Two data outputs are provided to increase design flexibility, RX Data A and RX Data B. RX Data A is CMOS/TTL compatible and RX Data B is raised ECL compatible.

**Figure 9. Differential Receiver Media Interface Circuitry**




Where: $R_T$ is a terminating resistor (100 Ω),
$Z_F$ is the filters impedance, and $Z_O$ is the characteristic impedance of the twisted pair (100 Ω).

The MC34055 powers up in a squelched and "link OK" state, after which minimum and maximum link test and maximum link fail timers are started. If valid data or a link pulse is received after the link test minimum timer but before the link fail maximum timer times out, the timers are reset and begin counting again. In the event of missing or incorrect link pulses, the MC34055 enters the link fail state whereby the LNKFL H status pin is asserted until valid data or link pulse activity appears at the receiver terminals.

Powering up in the squelched state assures that the data path to the data output pin (RX Data A/B) is disabled, and prevents noise at the receiver terminals (RX+/RX–), from being interpreted as valid input data. Once transitions appear at the receiver terminals, the smart squelch circuitry checks for the smart squelch requirements to unsquelch; an alternating sequence (1010... or 0101...) of pulses with amplitude of at least 525 mV. This requirement is met by the preamble of an IEEE 802.3 frame with good signal to noise ratio.

After a pulse is received and checked for proper polarity and amplitude, the pulse width is checked for proper duration. If the duration is to short or too long the smart squelch circuitry resets and begins to look again for a proper sequence. By requiring the differential pulses to meet amplitude and sequence requirements, it is unlikely that pulses due to crosstalk from coresident twisted pairs are capable of causing the receiver to unsquelch. If a positive pulse is received first and the differential driver is not transmitting, the receiver should unsquelch after three alternating pulses. If a negative pulse is received first, one additional pulse is required before unsquelch. If the differential driver is transmitting, three additional pulses are required to unsquelch.

After meeting the smart squelch requirements, the MC34055 will pull high the RX EN H pin and enable the path to the receive data pin (RX Data A/B) provided the MC34055 is not in the loop back test mode (Loop L low). If the receiver unsquelches, the receive enable pin remains high and the data path to the receive data pin remains enabled until transitions cease to exist at the receiver terminals. Valid data reception is also indicated by high/low transitions of the LNKFL H pin at 100 ms intervals. When transitions at the differential terminals cease, marking the end of frame activity, the receiver re–enters the squelch state, pulls low on the RX EN H pin, and begins accepting valid link pulses until the start of the next 802.3 frame.

If the MC34055 is requested to begin transmitting (TX EN H is asserted), and the receiver unsquelches simultaneously, there is a collision. Also, if the MC34055 driver enable pin is previously asserted and the receiver detects valid transition activity, the receiver Smart Squelch circuitry verifies the possibility of collision by requiring three extra transitions at the differential receiver before the unsquelch condition is reached. If unsquelch occurs, a collision condition exists. During all collision conditions the MC34055 asserts the CTL H status pin for the duration of the condition and for a time after the end of collision.

During a collision condition the receive and transmit paths are still both enabled allowing transparency to the media. Either the presence of simultaneous transmit and receive activity or the condition of the CTL H status pin can be used by the communications controller to acknowledge and react to the collision. In applications where a 10 MHz collision signal is required by an SIA, the combination of this status pin and the clock oscillator output can be logically combined to provide a 10 MHz output. If the DTE reacts to the collision and ceases transmitting, the MC34055 will decay to idle until a re–transmit is attempted.

### Crystal Oscillator

The MC34055 has an on–chip clock oscillator used to provide a reliable and accurate time reference to all the internal timers. The oscillator can be run with a crystal or driven at Pin 24 from an external clock source. Also provided is a buffered clock output which is useful if the MC34055 is to be used in a repeater or concentrator application.

**Table 1. The crystal used in the oscillator is subject to the following specifications.**

| | |
|---|---|
| Crystal Operating Mode | Fundamental |
| Crystal Cut Type | AT |
| Crystal External Shunt Capacitance | 7.0 pF Max |
| Crystal Resonant Mode | Series |
| Crystal Accuracy | ± 0.01% @ 25°C |
| Crystal Temperature Variance | 0.005% from 0° to 70°C |
| Crystal Series Resistance | 25 Ω Max, 17 Ω Typical |
| Crystal Operating Temperature Range | 0° to 70°C |

### LOOP L Test Mode

If the Loop L pin is low, the MC34055 is in a test mode whereby the data at the input pin (TX Data A/B) is being looped back internally to the receive data pin(RX Data A/B). In this mode the data path from the differential receiver terminals to the receive data output pins (RX Data A/B) is disconnected while the Smart Squelch functionality of the differential receiver is still operational. This test mode allows the DTE to test the MC34055 internal loop back circuitry since the data is looped back to the receive circuitry as close to the twisted pair interface as possible.

### Signal Quality Error Test

The MC34055 also provides the ability to test the collision detect circuitry without disabling either of the data paths. By pulling the SQE EN L pin low, a collision test is provided to the collision detect circuitry immediately following the last edge of a transmitted 802.3 frame. The test verifies the operability of the collision detect circuitry, operability is announced by the assertion of the CTL H pin for a period following a valid data transmission.

### Jabber Detection

The transmit circuitry of the MC34055 has the ability to monitor and shut down the differential driver in the event of a jabber condition. If transmission activity ever exceeds 20 ms minimum, the differential driver, the collision detect, and internal loop back circuits are disabled. To announce the presence of a jabber condition, both the CTL H and the JABB H status output pins are asserted. In order to end the jabber condition, the TX Data A/B input must stop toggling, or the TX EN H pin must be pulled low for a minimum of 500 ms. The status output pins have the ability to drive an external led and were added to facilitize network manageability. The jabber status outputs will not assert during power up or power down.

### Full Duplex Mode

The MC34055 can be operated in a full–duplex mode if required. When the FULLD L pin is pulled low the device will enter the full duplex mode. This mode allows the transmitter and driver to operate independently. Collision will not be announced and the internal loop back operation is disabled. The Signal Quality Error test, however, is still operational if enabled.

### Status Pins

The MC34055 has three status indicator pins capable of sourcing or sinking enough current to support an external LED. Status pin levels ("1" or "0") report the condition of the transceiver. Table 2 shows the combinations and significance.

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**Table 2**

| Status Pin | | | Condition |
|---|---|---|---|
| JABB H | CTL H | LNKFL H | |
| "0" | "1" | X | Collision condition or Signal Quality Error test. |
| "1" | "1" | X | Jabber condition |
| X | X | "0" | Link Failure. Incorrect or nonexistent link pulses, or lack of data at the receiver terminals. |
| X | X | "1" | Link "OK". Receiving link pulses. |
| X | X | "0101..." | Link "OK". Receiving valid data. |

### Test Select Pins

The MC34055 has three operation mode test select pins, Loop L, SQE EN L and FULLD L. The level of the pin determines the mode of operation. Table 3 shows the levels and corresponding conditions of the status pins.

**Table 3**

| Pin | Status | Condition |
|---|---|---|
| Loop L | "1" | Normal operating mode. Loop back occurs when the transmitter initiates and the receiver is receiving link pulses. The RX EN H pin follows the TX EN H pin and the transmit data appears on the RX Data A/B output pin being used. |
| | "0" | Loop back test mode. The transmit circuit is looped back internally as close to the differential receive circuit as possible. In this mode the RX EN H pin follows the TX EN H pin and the transmit data appears on the RX Data A/B output pin being used. Any received data other than link pulses are ignored and the receiver will not unsquelch or announce collision. |
| SQE EN L | "0" | Normal operating mode. Concurrent transmit and receive activity results in a collision condition. |
| | "1" | Test enabled. An internal test is run on the collision circuitry and the CTL H pin is asserted for a time window following the last positive packet edge. Data transmission and reception is undisturbed. |
| FULLD L | "1" | Normal operating mode. Internal loop–back is operable and collision is announced. |
| | "0" | Internal loop–back is disabled and collision will not be announced. Signal Quality Error test is still operable. |

## APPLICATIONS INFORMATION

The MC34055 implements the physical layer of a 10BASE–T application of IEEE 802.3. It provides the physical connection to the media (twisted pair) and the services required by the MAC sublayer of the Data Link Layer. Two interfaces are defined in the IEEE 802.3 specification of the physical layer; one is the MDI providing connection to the twisted pair; and the other is the AUI providing connection to the encoder/decoder function of the Data Link Layer. While the MC34055 provides the connection to the twisted pair, a CMOS and raised ECL interface is provided instead of an AUI.

The MC34055 implements the twisted pair interface of the physical layer in a 802.3 10BASE–T application but circuitry must be added if an AUI is desired, (see Figure 10 for suggested schematic). For example, an external MAU application requires the AUI and a twisted pair interface. A chip capable of realizing the AUI interface is the Texas Instruments SN75ALS085. This IC has an AUI interface and another interface which is compatible with the MC34055. The differential input of the 75ALS085 can be used for the TX+/TX– terminals of the AUI. The differential drivers of the 75ASL085 can be used as the RX+/RX– and the COL+/COL– terminals of the AUI. The other interface of the 75ALS085 then will interface to the MC34055 by three paths shown in the application suggestion. The application accounts for all the inputs/outputs of an external MAU.

Embedded applications do not require a full AUI and a MC10116 can be used to interface between the raised ECL interfaces of the MC34055 and the AUI of existing encoder/decoder chips. The MC10116 is a MECL 10k Triple Line Receiver with typical propagation delay and rise and fall times (20% to 80%) of 2.0 ns. Figure 11 shows the use of the MC10116 with the MC34055 and the AMD 7992 SIA.

In a multi–port repeater, or hub, a port is required for each DTE connected to the IEEE 802.3 network. This port consists of two connections, one for the TX+/TX– pair and another for the RX+/RX– pair. The repeater unit then multiplexes these lines so that all of the stations are capable of transmitting to or receiving from all the other stations on the network. This establishes the need for a transceiver without an AUI interface. If an AUI is present with each 10BASE–T transceiver, chip count is increased because there is a requirement to convert from balanced to unbalanced lines before multiplexing.

An application suggestion for the use of the MC34055 used in a multiport repeater is shown in Figure 6. Here the receive and transmit lines for the 10BASE–T transceivers are multiplexed by the hub hardware.

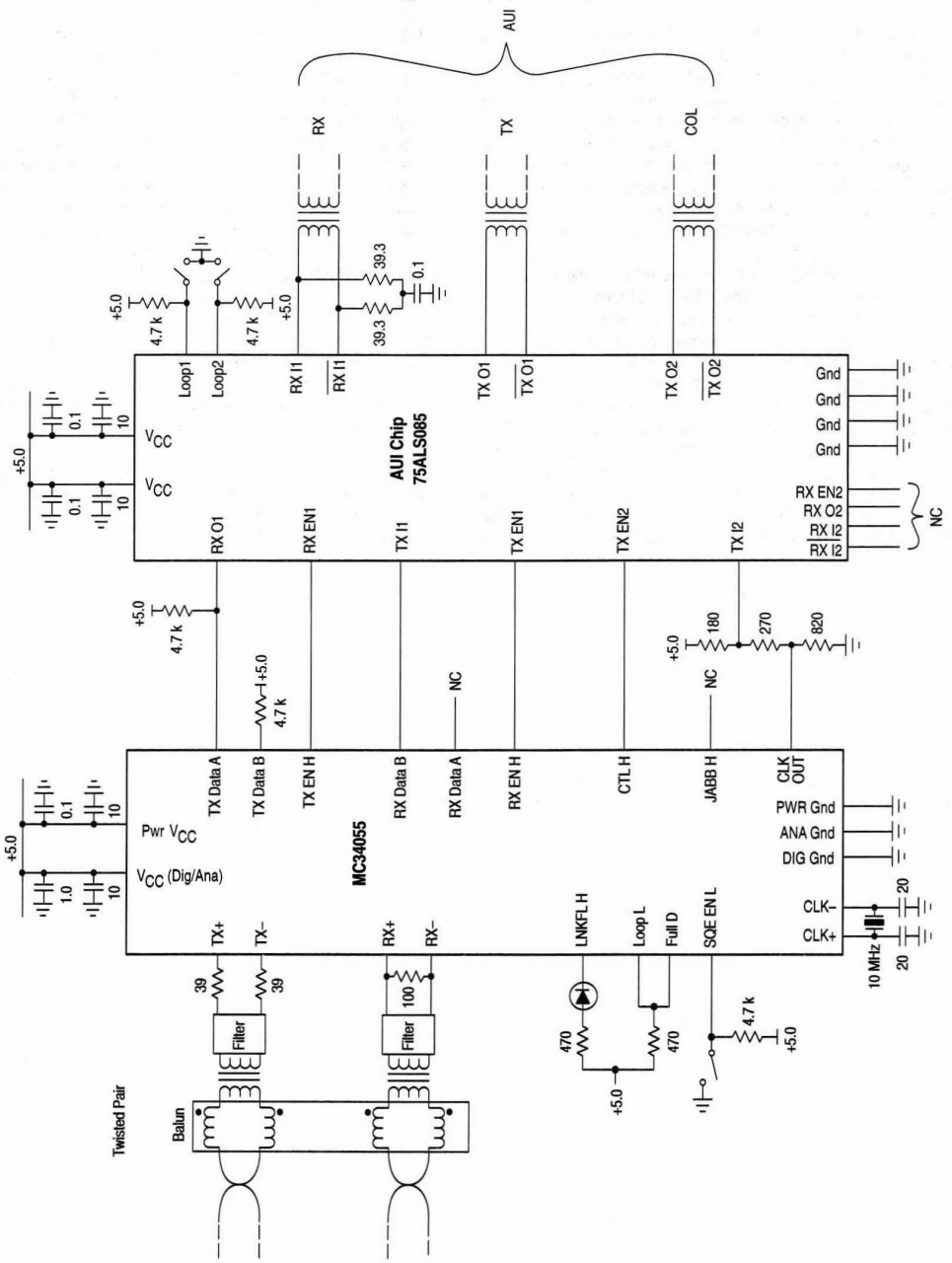
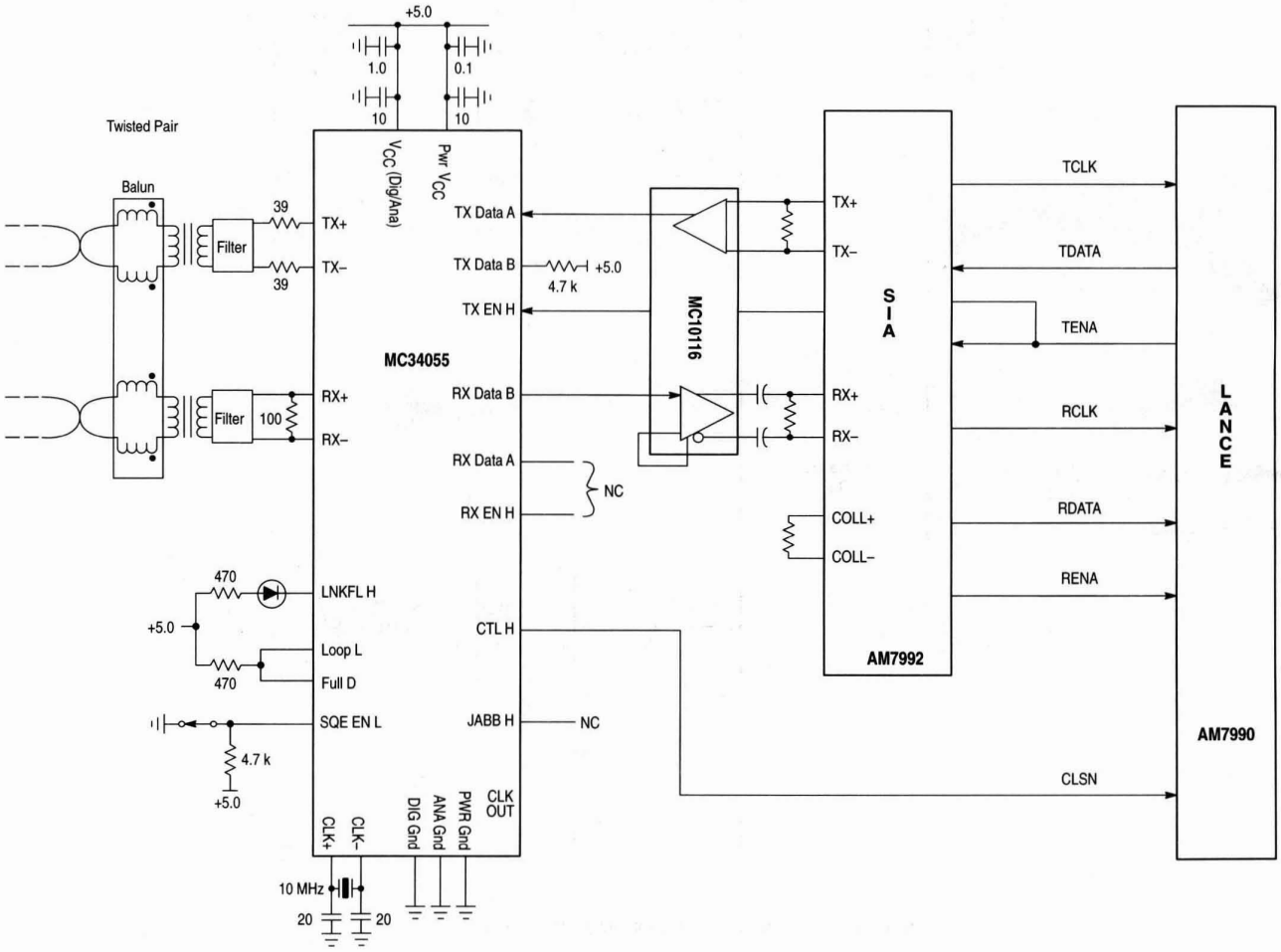



Figure 10. External MAU Application

**Figure 11. Internal MAU Application**



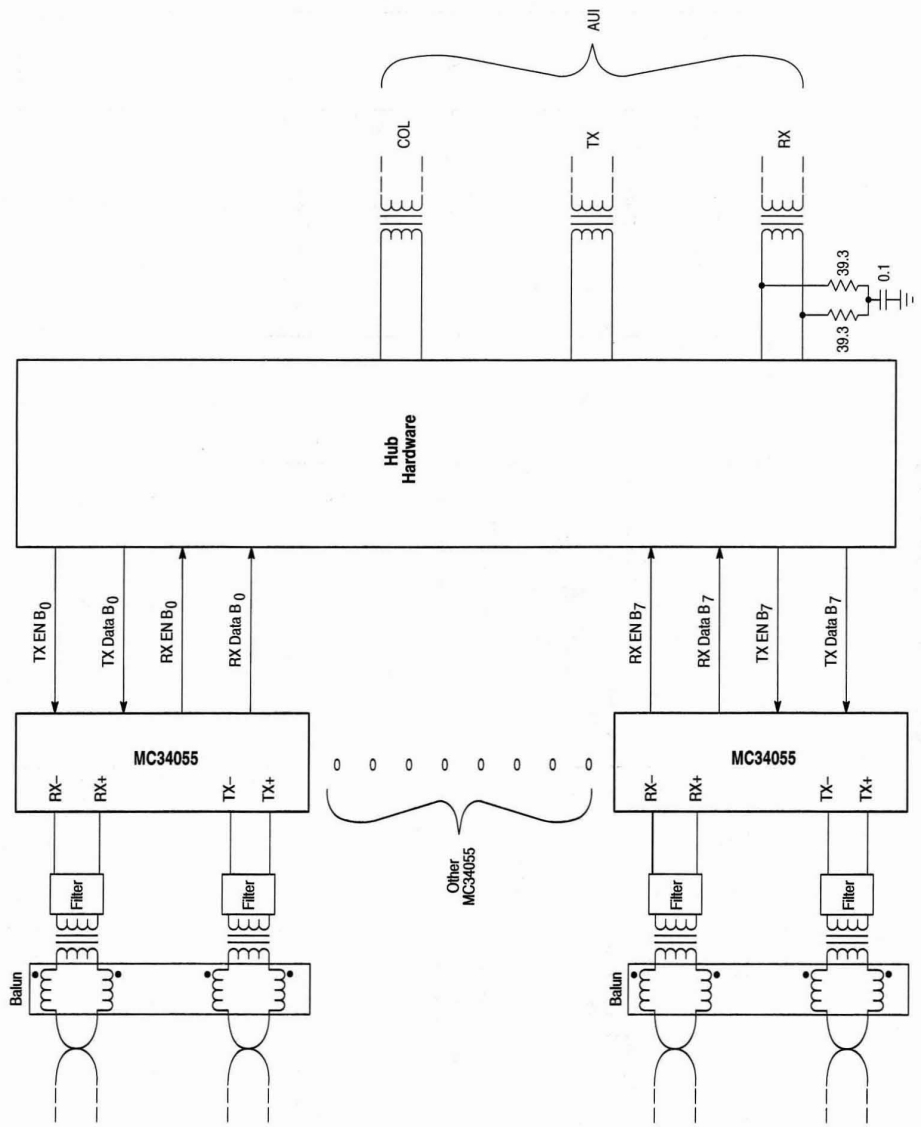



Figure 12. 10BASE–T Connecentrator Application

MOTOROLA

# MC34058
# MC34059

## Hex EIA-485 Transceiver with Three-State Outputs

**HEX EIA–485 TRANSCEIVER with THREE–STATE OUTPUTS**

**SEMICONDUCTOR TECHNICAL DATA**

The Motorola MC34058/9 Hex Transceiver is composed of six driver/receiver combinations designed to comply with the EIA–485 standard. Features include three–state outputs, thermal shutdown for each driver, and current limiting in both directions. This device also complies with EIA–422 and CCITT Recommendations V.11 and X.27.

The devices are optimized for balanced multipoint bus transmission at rates to 20 MBPS (MC34059). The driver outputs/receiver inputs feature a wide common mode voltage range, allowing for their use in noisy environments. The current limit and thermal shutdown features protect the devices from line fault conditions.

The MC34058/9 is available in a space saving 7.0 mm 48 lead surface mount quad package designed for optimal heat dissipation.

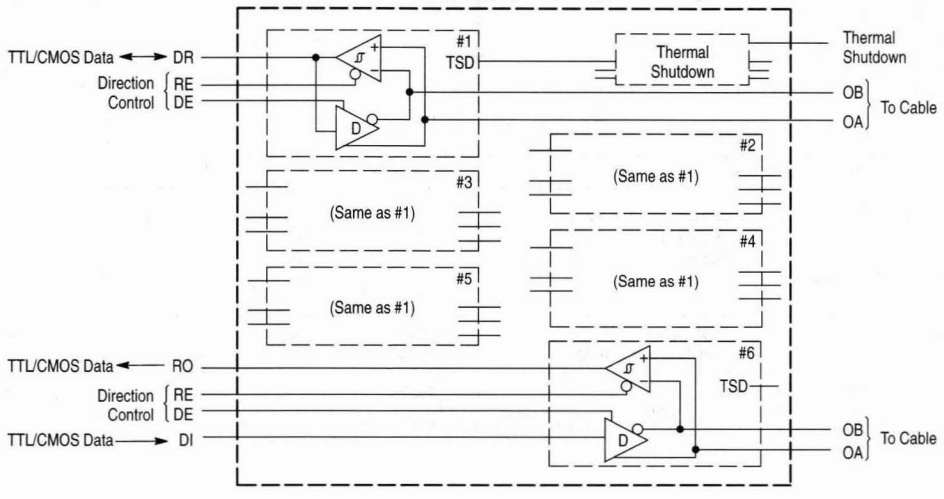
- Meets EIA–485 Standard for Party Line Operation
- Meets EIA–422A and CCITT Recommendations V.11 and X.27
- Operating Ambient Temperature: 0°C to +70°C
- Common Mode Driver Output/Receiver Input Range: –7.0 to +12 V
- Positive and Negative Current Limiting
- Transmission Rates to 14 MBPS (MC34058) and 20 MBPS (MC34059)
- Driver Thermal Shutdown at 150°C Junction Temperature
- Thermal Shutdown Active Low Output
- Single +5.0 V Supply, ±10%
- Low Supply Current
- Compact 7.0 mm 48 Lead TQFP Plastic Package

**FTA SUFFIX**
PLASTIC PACKAGE
CASE 932
(Thin QFP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC34058FTA | $T_A$ = 0° to +70°C | TQFP–48 |
| MC34059FTA | | |

**Representative Block Diagram**




This device contains 1,399 active transistors.

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | −0.5, 7.0 | Vdc |
| Input Voltage (Driver Data, Enables) | $V_{in}$ | 7.0 | Vdc |
| Applied Driver Output Voltage When in Three–State Condition ($V_{CC}$ = 5.0 V) | $V_Z$ | −10, 14 | Vdc |
| Applied Driver Output Voltage When $V_{CC}$ = 0 V | $V_X$ | ±14 | Vdc |
| Output Current | $I_O$ | Self Limiting | – |
| Storage Temperature | $T_{stg}$ | −65, 150 | °C |

**NOTE:** Devices should not be operated at these limits. The "Recommended Operating Conditions" provides for actual device operation.

## RECOMMENDED OPERATING CONDITIONS (All limits are not necessarily functional concurrently.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.5 | 5.0 | 5.5 | Vdc |
| Input Voltage (All Inputs Except Receiver Inputs) | $V_{in}$ | 0 | – | $V_{CC}$ | Vdc |
| Driver Output Voltage in Three–State Condition, Receiver Inputs, or When $V_{CC}$ = 0 V | $V_{CM}$ | −7.0 | – | 12 | Vdc |
| Driver Output Current (Normal Data Transmission) | $I_O$ | −60 | – | 60 | mA |
| Operating Ambient Temperature | $T_A$ | 0 | – | 70 | °C |

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## ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{CC}$ = 5.0 V ± 10%)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DRIVER CHARACTERISTICS** | | | | | |
| Output Voltage | | | | | |
| Single Ended, $I_O$ = 0 | $V_O$ | 0 | – | $V_{CC}$ | Vdc |
| Differential, Open Circuit ($I_O$ = 0) | $\|V_{OD1}\|$ | 1.5 | – | – | Vdc |
| Differential, $R_L$ = 54 Ω | $\|V_{OD2}\|$ | 1.5 | – | – | Vdc |
| Change in Differential Voltage (Note 1), $R_L$ = 54 Ω | $\|\Delta V_{OD2}\|$ | – | – | 200 | mVdc |
| Differential, $R_L$ = 100 Ω | $\|\Delta V_{OD2A}\|$ | 2.0 | – | – | Vdc |
| Change in Differential Voltage (Note 1), $R_L$ = 100 Ω | $\|V_{OD2A}\|$ | – | – | 200 | mVdc |
| Common Mode Voltage, $R_L$ = 54 Ω | $V_{OCM}$ | – | – | 3.0 | Vdc |
| Common Mode Voltage Change, $R_L$ = 54 Ω | $\|\Delta V_{OCM}\|$ | – | – | 200 | mVdc |
| Output Current (Each Output) | | | | | mA |
| Short Circuit Current, −7.0 V ≤ $V_O$ ≤ 12 V | $I_{OS}$ | −250 | – | 250 | |
| Driver Data Inputs | | | | | Vdc |
| Low Level Voltage | $V_{ILD}$ | – | – | 0.8 | |
| High Level Voltage | $V_{IHD}$ | 2.0 | – | – | |
| Clamp Voltage ($I_{in}$ = −18 mA) | $V_{IKD}$ | −1.5 | – | – | |
| Thermal Shutdown Junction Temperature | $T_{JTS}$ | – | 150 | – | °C |
| **RECEIVER CHARACTERISTICS** | | | | | |
| Input Threshold $R_O$ = High | $V_{th}$ | – | – | 200 | mVdc |
| $R_O$ = Low | | −200 | – | – | |
| Input Loading (Driver Disabled) | | – | 0.36 | 1.0 | U.L. |
| Hysteresis | $V_H$ | – | 100 | – | mV |
| Output Voltage High ($I_{OH}$ = −400 µA) | $V_{OHR}$ | 2.4 | – | – | Vdc |
| Low ($I_{OL}$ = 4.0 mA) | $V_{OLR}$ | – | – | 0.4 | |
| Output Short Circuit Current | $I_{OSR}$ | – | 45 | 85 | mA |
| Output Leakage Current When in Three–State Mode | $I_{OLKR}$ | – | – | 20 | µA |

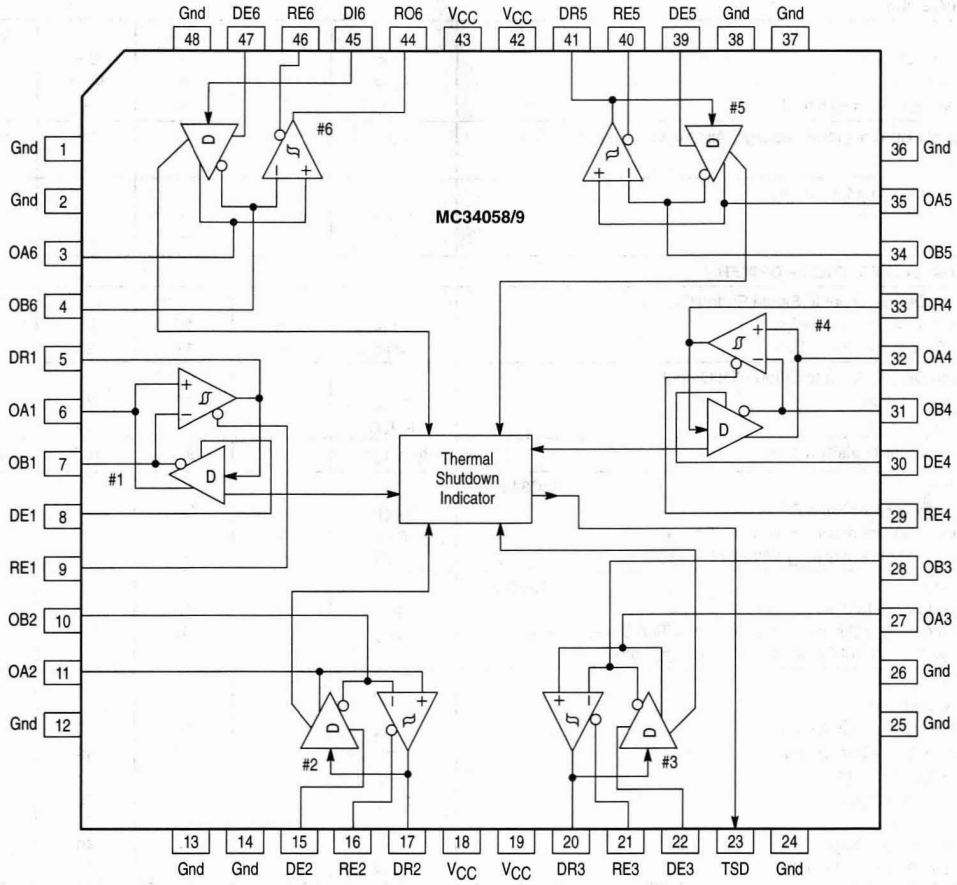
**NOTE:** 1. Input switched from low to high.

**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC}$ = 5.0 V ± 10%)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **MISCELLANEOUS** | | | | | |
| Enable Inputs | | | | | Vdc |
| Low Level Voltage | $V_{ILE}$ | 0 | – | 0.8 | |
| High Level Voltage | $V_{IHE}$ | 2.0 | – | $V_{CC}$ | |
| Clamp Voltage ($I_{in}$ = –18 mA) | $V_{IKE}$ | –1.5 | – | – | |
| Power Supply Current (Total Package, All Outputs Open, Enabled or Disabled) | $I_{CC}$ | – | 18 | 28 | mA |
| Thermal Shutdown Output Voltage | | | | | Vdc |
| High | $V_{OHT}$ | 2.4 | – | – | |
| Low | $V_{OLT}$ | 0 | – | 0.8 | |
| **TIMING CHARACTERISTICS – DRIVER** | | | | | |
| Propagation Delay – Input to Single Ended Output | | | | | ns |
| Input to Output – Low–to–High | $t_{PLH}$ | – | 10 | 20 | |
| Input to Output – High–to–Low | $t_{PHD}$ | – | 11 | 20 | |
| Propagation Delay – Input to Differential Output | | | | | ns |
| Input Low–to–High | $t_{PLHD}$ | – | 15 | 23 | |
| Input High–to–Low | $t_{PHLD}$ | – | 15 | 23 | |
| Differential Output Transition Time | $t_{DR}$, $t_{DF}$ | – | 9.0 | 10.7 | ns |
| Skew Timing MC34058 | | | | | ns |
| $\lvert t_{PLHD} - t_{PHLD} \rvert$ for Each Driver | $t_{SK1}$ | 0 | 0.1 | – | |
| Maximum – Minimum $t_{PLHD}$ Within a Package | $t_{SK2}$ | 0 | – | 8.0 | |
| Maximum – Minimum $t_{PHLD}$ Within a Package | $t_{SK3}$ | 0 | – | 6.0 | |
| Skew Timing MC34059 | | | | | ns |
| $\lvert t_{PLHD} - t_{PHLD} \rvert$ for Each Driver | $t_{SK7}$ | 0 | 0.1 | – | |
| Propagation Delay Difference Between Any Two Drivers (Same Package or Different Packages at Same $V_{CC}$ and $T_A$) | $t_{SK8}$ | – | <4.0 | – | |
| Enable Timing | | | | | ns |
| Single Ended Outputs | | | | | |
| Enable to Active High Output | $t_{PZH}$ | – | 15 | 40 | |
| Enable to Active Low Output | $t_{PZL}$ | – | 25 | 40 | |
| Active High to Disable | $t_{PHZ}$ | – | 12 | 25 | |
| Active Low to Disable | $t_{PLZ}$ | – | 10 | 25 | |
| Differential Outputs | | | | | |
| Enable to Active Output | $t_{PZD}$ | – | – | 40 | |
| Enable to Three–State Output | $t_{PDZ}$ | – | – | 25 | |
| **TIMING CHARACTERISTICS – RECEIVER** | | | | | |
| Propagation Delay | | | | | ns |
| Input to Output – Low–to–High | $t_{PLHR}$ | – | 16 | 23 | |
| Input to Output – High–to–Low | $t_{PHLR}$ | – | 16 | 23 | |
| Skew Timing | | | | | ns |
| $\lvert t_{PLHR} - t_{PHLR} \rvert$ for Each Receiver | $t_{SK4}$ | 0 | 1.0 | – | |
| Maximum – Minimum $t_{PLHR}$ Within a Package | $t_{SK5}$ | 0 | – | 3.0 | |
| Maximum – Minimum $t_{PHLR}$ Within a Package | $t_{SK6}$ | 0 | – | 3.0 | |
| Skew Timing<br>Propagation Delay Difference Between Any Two Receivers in Different Packages at Same $V_{CC}$ and $T_A$ (MC34059 Only) | $t_{SK9}$ | – | <5.0 | – | ns |
| Enable Timing | | | | | ns |
| Single Ended Outputs | | | | | |
| Enable to Active High Output | $t_{PZHR}$ | – | 15 | 22 | |
| Enable to Active Low Output | $t_{PZLR}$ | – | 25 | 30 | |
| Active High to Disable | $t_{PHZR}$ | – | 12 | 25 | |
| Active Low to Disable | $t_{PLZR}$ | – | 10 | 25 | |

7

## Block Diagram and Pinout




**PINOUT SUMMARY**

| | | | |
|---|---|---|---|
| OA | NonInverting Output/Input | DE | Driver Enable, Active High (TTL) |
| OB | Inverting Output/Input | $\overline{RE}$ | Receiver Enable, Active Low (TTL) |
| DR | Driver Input/Receiver Output (TTL) | $\overline{TSD}$ | Thermal Shutdown Indicator |
| DI6 | #6 Driver Input (TTL) | $V_{CC}$ | Connect 4 Pins to 5.0 V, ±10% |
| RO6 | #6 Receiver Output (TTL) | Gnd | Connect 12 Pins to Circuit Ground |

**Figure 1. $V_{OD}$ and $V_{OS}$ Test Circuit**

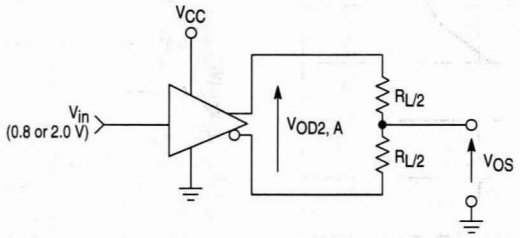



**Figure 2. $V_{OD}$ and $V_{CM}$ Test Circuit**

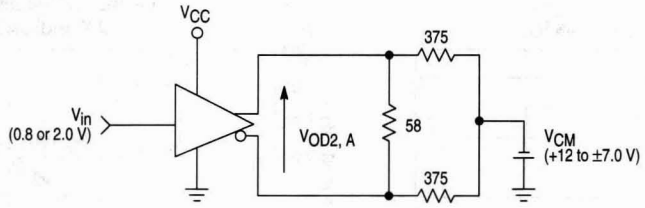



**Figure 3. $V_{OD}$ AC Test Conditions**

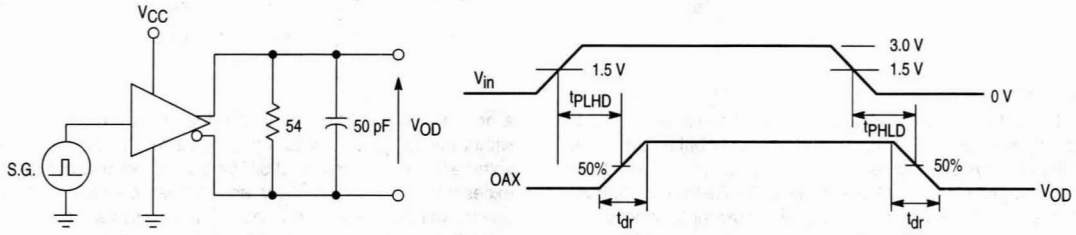



**Figure 4. $V_{OH}$ and $V_{OL}$ AC Test Conditions**

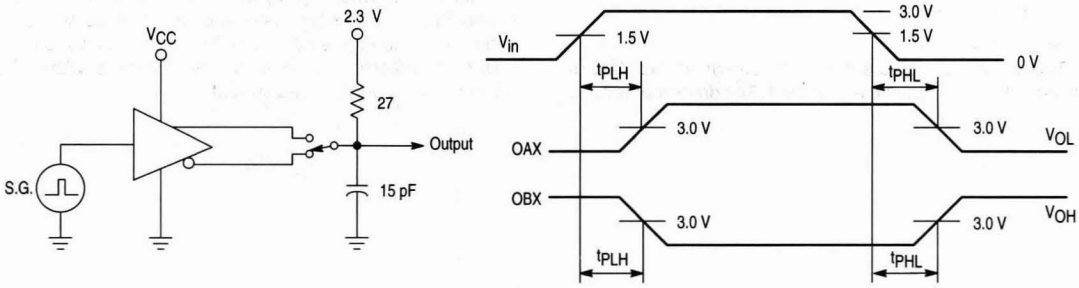


Figure 5. $V_{OH}$ versus $I_{OH}$

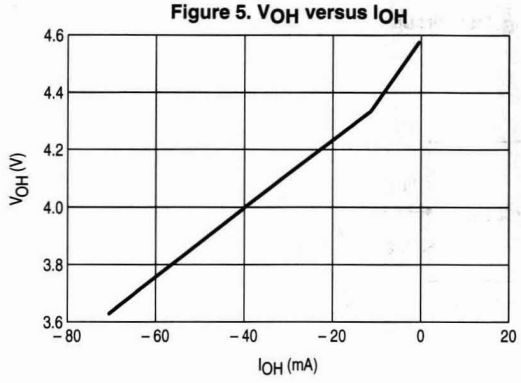



Figure 6. $V_{OL}$ versus $I_{OL}$

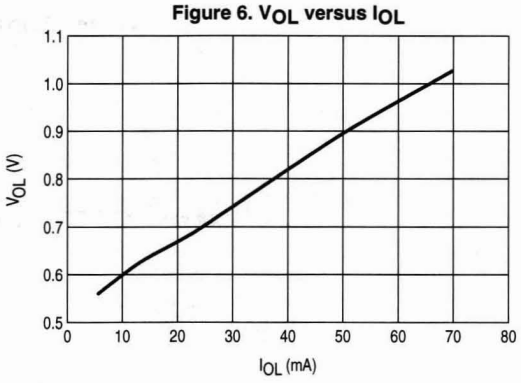



Figure 7. $V_{OD}$ versus $I_{OL}$

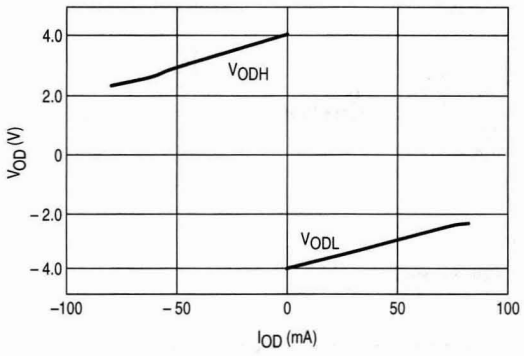
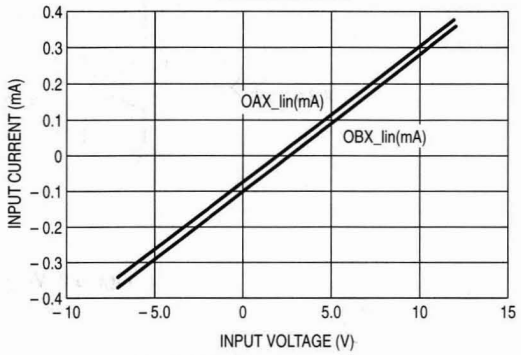



Figure 8. Input Characteristics of OAX and OAB




7

## Description

The MC34058/9 is a differential line driver designed to comply with EIA–485 Standard for use in balanced digital multipoint systems containing multiple drivers. The drivers also comply with EIA–422–A and CCITT Recommendations V.11 and X.27. Positive and negative current limiting of the drivers meet the EIA–485 requirement for protection from damage in the event that two or more drivers try to transmit simultaneously on the same cable. Data rates in excess of 10 MBPS are possible, depending on the cable length and cable characteristics. Only a single power supply, 5.0 V ±10% is required.

## Driver Inputs

The driver inputs and enable logic determine the state of the outputs in accordance with Table 1. The driver inputs have a nominal threshold of 1.2 V, and the voltage must be kept within the range of 0 V to $V_{CC}$ for proper operation. If the voltage is taken more than 0.5 V below ground or above $V_{CC}$, excessive currents will flow and proper operation of the drivers will be affected. An open Pin is equivalent to a logic high, but good design practices dictate that inputs should never be left open. The inputs are TTL type and their characteristics are unchanged by the state of the enable pins.

## Driver Outputs

Each output (when active) will be a low or a high voltage, depending on the input state and the load current (see Tables 1, 2 and Figures 2 and 3). The graphs apply to each driver, regardless of how many other drivers within the package are supplying load current.

**Table 1. Driver Truth Table**

| Driver Data Inputs | Enables | | Outputs | |
|---|---|---|---|---|
| | DEX | REX | OAX | OBX |
| H | H | H | H | L |
| L | H | H | L | H |
| X | L | H | Z | Z |
| X | H | L | Not Defined | Not Defined |

The outputs will be in a high impedance state when:
a) The Enable inputs are set according to Table 1;
b) The junction temperature exceeds the trip point of the thermal shutdown circuit. When in this condition, the output's source and sink capability are shut off, and a leakage current of less than 20 μA will flow. Disabled outputs may be taken to any voltage between –7.0 V and 12 V without damage to internal circuitry.

The drivers are protected from short circuits by two methods:
a) Current limiting is provided at each output, in both the source and sink direction, for shorts to any voltage within the 12 V to –7.0 V range, with respect to circuit ground. The short circuit current will flow until the fault is removed, or until the thermal shutdown activates. The current limiting circuit has a negative temperature coefficient and requires no resetting upon removal of the fault condition.
b) A thermal shutdown circuit disables the outputs when the junction temperature reaches +150°C, ± 20°C. The thermal shutdown circuit has a hysteresis of ~ 12°C to prevent oscillations. When this circuit activates, the output stage of each driver is put into the high impedance mode, thereby shutting off the output currents. However, the remainder of the internal circuitry remains biased and the outputs will become active once again as the IC cools down.

### Receiver Inputs

The receiver inputs and enable logic determine the state of the receiver outputs in accordance with Table 2. Each receiver input pair has a nominal differential threshold of at most 200 mV (Pin OAX with respect to OBX) and a common mode voltage range of –7.0 V and 12 V must be maintained for proper operation. A nominal hysteresis of 100 mV is typical. The receiver input characteristics are shown in Figure 8. When the inputs are in the high impedance state, they remain capable of the common mode voltage range of –7.0 V to 12 V.

### Receiver Outputs

The receiver outputs are TTL type outputs and act in accordance with Table 2.

### Enable Logic

Each driver output is active when the Driver Enable input is true according to Table 1. Each receiver output is active when the Receiver Enable input is true according to Table 2.

The Enable inputs have a nominal threshold of 1.2 V and their voltage must be kept within the range of 0 V and $V_{CC}$ for proper operation. If the voltage is taken more than 0.5 V below ground or above $V_{CC}$, excessive currents will flow and proper operation of the drivers will be affected. An open pin is equivalent to a logic high, but good design practices dictate that inputs should never be left open. The enable inputs are TTL compatible. Since the same pins are used for driver input and receiver output, care must be taken to make sure that DEX and $\overline{REX}$ are not both enabled. This may result in corruption of both the transmitted and received data.

**Table 2. Receiver Truth Table**

| Receiver Data Inputs | Enables | | Outputs |
|---|---|---|---|
| OAX–OBX | DEX | $\overline{REX}$ | DRX |
| ≥ +200 mV | L | L | H |
| ≤ –200 mV | L | L | L |
| X | L | H | Z |
| X | H | L | Not Defined |

## APPLICATIONS

The MC34058/9 was designed to meet EIA/TIA–422 and EIA/TIA–485 standards. EIA/TIA–422 specifies balanced point–to–point transmission with the provision for multiple receivers on the line. EIA/TIA–485 specifies balanced point–to–point transmission and allows for multiple drivers and receivers on the line. Refer to EIA/TIA documents for more details. Figure 9 shows a typical EIA/TIA–422 example. Figure 10 shows a typical EIA/TIA–485 example.

**Figure 9. Typical EIA/TIA–422 Application**

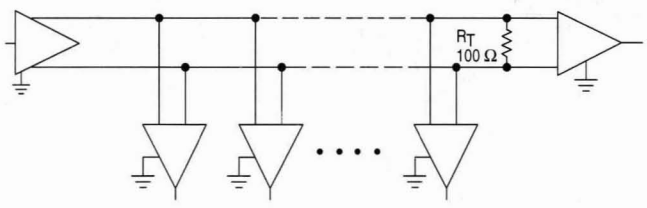
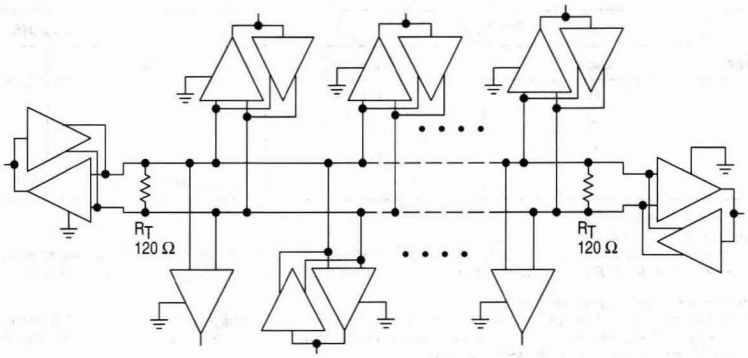


**Figure 10. Typical EIA/TIA–485 Application**




EIA/TIA–422 specifications require the ability to drive at least 10 receivers of input impedance of greater than or equal to 4.0 KΩ plus the 100 Ω termination resistor. This protocol was intended for unidirectional transmission. EIA/TIA–485 is capable of bidirectional transmission by allowing multiple drivers and receivers on the same twisted pair segment. The loading of the twisted pair segment can be up to 32 Unit Loads (U.L.) plus the two 120 Ω terminating resistors. The U.L. definition is shown in Figure 11.

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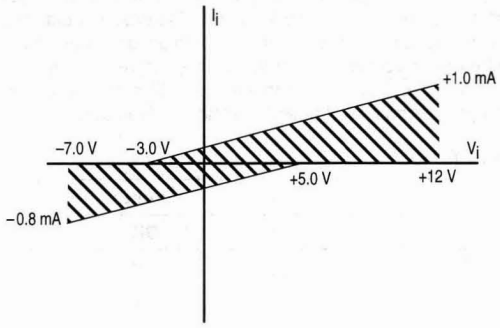
**Figure 11. TIA/EIA–485 Unit Load Definition**




**Calculating Power Dissipation for the MC34058/9 Hex–Transceiver.**

The operational temperature range is listed as 0°C to 70°C to satisfy both EIA/TIA–485 and EIA/TIA–422 specifications. However, a lower ambient temperature may be required depending on the specific board layout and/or application.

Using a first order approximation for heat transfer, the maximum power which may be dissipated by the package is determined by (see Appendix A for more details);

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{\theta ja} \quad [1]$$

where:

θja = package thermal resistance (see Appendix A)

$T_{Jmax}$ = Maximum Junction Temperature. Since the thermal shutdown feature has a trip point of 150°C ± 20°, $T_{Jmax}$ is selected to be +130°C.

$T_A$ = Ambient Operating Temperature.

The power generated within the package is then;

$$PD = \left\{\left[\left(V_{CC} - V_{OH_1}\right) \cdot I_{OH_1}\right] + V_{OL_1} \cdot I_{OL_1}\right\} + ..$$

$$(each\_driver).. + \left\{\left[\left(V_{CC} - V_{OH_6}\right) \cdot I_{OH_6}\right] + V_{OL_6} \cdot I_{OL_6}\right\} + V_{CC} \cdot I_{CCQ} \quad [2]$$

As indicated in the equation, the part of Equation 2 consisting of $I_{OH}$, $V_{OH}$, $I_{OL}$ and $V_{OL}$ must be calculated for each of the drivers and summed for the total power dissipation estimate. The last term can be considered the quiescent power required to keep the IC operational and is measured with the drivers idle and unloaded. The $V_{OH}$ and $V_{OL}$ terms can be determined from the output current versus output voltage curves which provide driver output characteristics.

Example 1 estimates thermal performance based on current requirements.

**Example 1. Balanced and Unbalanced Operation**

$I_{OL}$ = 50 mA and $I_{OH}$ = ±50 mA for each driver. $V_{CC}$ = 5.0 V.
How many drivers can be used? (Typical power supply current $I_{CCQ}$ = 18 mA.)

Solution:
$I_{CCQ}$ = 0.018 A
The quiescent power is given by: $P_Q = I_{CCQ} \cdot V_{CC}$, and is equal to $P_Q$ = 0.09 W.

**Balanced Operation:**

To determine the amount of power dissipated by each output stage we need to know the differential output voltage for the output current required. Figure 7 shows that for $I_{OH}$ and $I_{OL}$ differential of 50 mA, $V_{ODH}$ and $V_{ODL}$ are:

$V_{OD}$ = |3.0|, and $I_{OL} = |I_{OH}| = I_{Out}$ = 0.050 A.

And the power dissipated by each driver is given by;

$P_{DrvB} = I_{Out} \cdot \left(V_{CC} - V_{OD}\right)$ and equal to

$P_{DrvB}$ = 0.10 W.

**Unbalanced Operation:**

To determine the amount of power dissipated by each output stage we need to know the single–ended output voltage for the output current required. Figures 5 and 6 shows that for an $I_{OH}$ and $I_{OL}$ of ±50 mA,

$V_{OH}$ = 3.9 V $V_{OL}$ = 0.895 V

And the power dissipated by each driver is calculated by;

$P_{DrvU} = \left(V_{CC} - V_{OH}\right) \cdot |I_{OH}| + V_{OL} \cdot I_{OL}$

and equal to

$P_{DrvU}$ = 0.10 W.

(For this example, balanced operation is assumed.)
Summing the quiescent and driver power for 6 transceivers operating in a package produces;

$$P_{DTotal} = P_Q + 6 \cdot P_{DrvB}, \text{ and equal to } P_{DTotal} = 0.69 \text{ W}.$$

For the MC34058/9, the thermal resistance is capable of a wide range. The ability of the package to dissipate power depends on board type and temperature, layout and ambient temperature (see Appendix A). For the purposes of this example the thermal resistance can range from 40°C/W to 100°C/W;

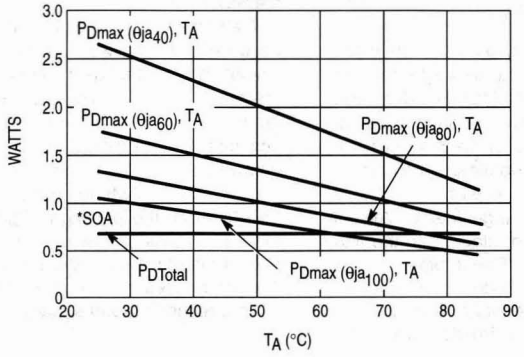
$$\theta ja = j,\ j = 40, 60, .. 100°C/W.$$

Varying the ambient operating temperature $T_A$ = 25, 30, .. 85°C; specifying a maximum junction temperature to avoid thermal shutdown $T_{Jmax}$ = 130°C; and using the first order approximation for maximum power dissipation;

$$P_{Dmax(\theta ja)},\ T_A = \frac{T_{Jmax} - T_A}{\theta ja}$$

produces a set curves that can be used to determine a Safe Operating Area for the specific application. $P_{DTotal}$ is graphed with $P_{Dmax}$ to provide a reference.

**Graph of Maximum Power Dissipation Possible for a Particular θja and Ambient Temperature**




* Safe Operating Area (SOA), is an operating power, $P_{DTotal}$, less than $P_{Dmax}$.

So all the drivers in the package can be used if the thermal resistance and/or the ambient temperature is low enough.

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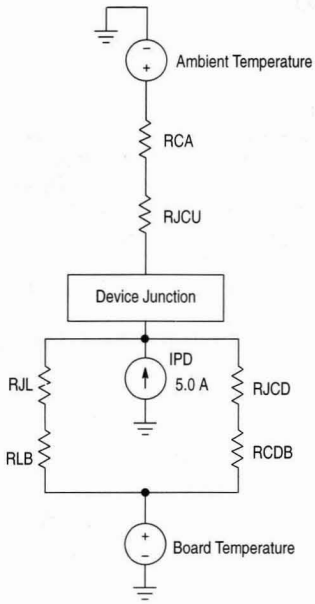
## Appendix A. Optimizing the Thermal Performance of the MC34058/9

**Figure 12. Electrical Model of Package Heat Transfer**




An equivalent electrical circuit for the thermal model for the MC34058/9 package is shown in Figure 12. It is a simplified model that shows the dominant means of heat transfer from the thermally enhanced 48–ld package used for the MC34058/9. The model is a first order approximation and is intended to emphasize the need to consider thermal issues when designing the IC into any system. It is however customary to use similar models and Equation 1 to estimate device junction temperatures.

Equation 1 is the common means of using the thermal resistance of a package to estimate junction temperature in a particular system.

$$T_J = (P_D \cdot \theta jx) + T_A \qquad [1]$$

The term θjx in Equation 1 is usually quoted as a øja value in °C/Watt. However, since the 48–ld package for the MC34058/9 has been thermally enhanced to take advantage of other heat sinking potentials, it must be modified. θjx must actually be considered a composite of all the heat transfer paths from the chip. That is, the three dominant and parallel paths shown in Figure 12. Of those three paths, potentially the most effective is the corner package leads. This is because these corner leads have been attached to the flag on which the silicon die is situated. These pins can be connected to circuit board ground to provide a more efficient conduction path for internal package heat. This path is modeled as the Rjl (junction–to–leads) and Rlb (leads–to–board) combination in Figure 12. This path provides the most effective way of removing heat from the device provided that there is a viable temperature potential (i.e. heat sinking source) to conduct towards. However, if it is not properly considered in the system design, the other paths, (Rjcd + Rcdb) and (Rjcu + Rca) attain greater importance and must be more carefully considered.

So Equation 1, modified to reflect a more complete heat transfer model becomes;

$$T_J = T_A \cdot \frac{\left(\frac{1}{\frac{1}{Rjcd} + \frac{1}{Rjlb}}\right)}{\left(\frac{1}{\frac{1}{Rjcd} + \frac{1}{Rjlb}}\right) + Rjca} + \ldots \qquad [2]$$

$$\ldots T_B \cdot \frac{Rjca}{\left(\frac{1}{\frac{1}{Rjcd} + \frac{1}{Rjlb}}\right) + Rjca} + PDISS \cdot \theta ja$$

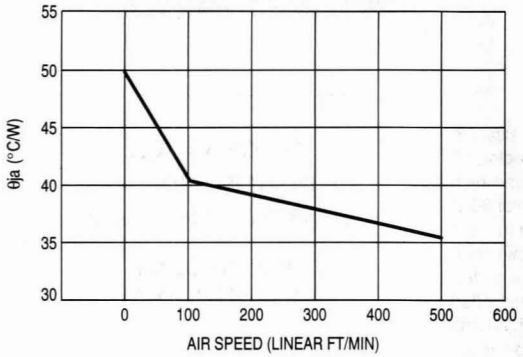
where;

$T_J$= Junction Temperature
$T_A$ = Ambient Temperature
$T_B$ = Board Temperature
$P_{DISS}$ = Device Power
and θja = Total Thermal Resistance and is composed the parallel combination of all the heat transfer paths from the package.

While Equation 2 is still only a first order approximation of the heat transfer paths of the MC34058/9, at least now it includes consideration for the most effective heat transfer path for the MC34058/9; the board to which the device is soldered. The modified equation also better serves to explain how external variables, namely the board and ambient temperatures, affect the thermal performance of the MC34058/9.

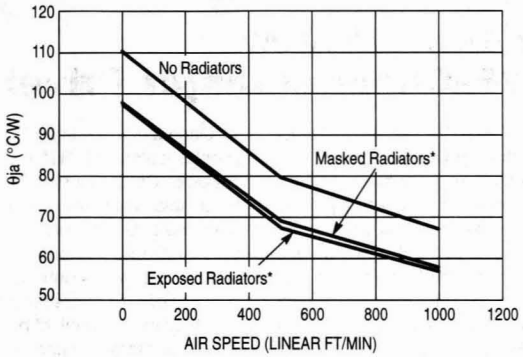
Methods of removing heat via the flag connected pins can be classified into two means; conduction and convection. Radiation is omitted as the contribution is small compared to the other means. Conduction is by far the best method to draw heat away from the MC34058/9 package. This is best accomplished by using a multilayer board with generous ground plane. In this case, the flag connected pins can be connected directly to the ground plane to maximize the heat transfer from the package. Figure 13 shows the results of thermal measurements of a board with an external ground plane (the actual ground area was approximately 6 1/4 $in^2$). The thermal leads are connected to the board ground plane per the recommended strategy.

**Figure 13. Thermal Resistance (θja) for Board with Large External Ground Plane**




θjc for the package on this board is 25 ±20% depending on the location of the package on the board.

**Figure 14A. Thermal Resistance (θja) for Board Without Ground Plane**




* Masked radiators were covered by a solder mask. Exposed radiators were bare copper.

**Figure 14B. Layout Used for Thermal Resistance Measurements in Figure 14A**

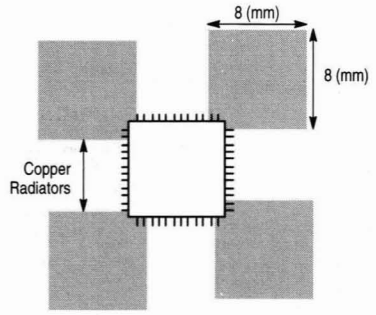



**Figure 15. Placement of Thermal Vias to Enhance Heat Transfer to Ground Plane**

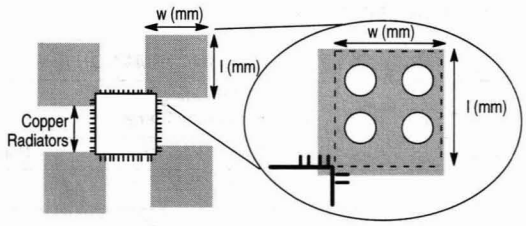



Figure 14A on the other hand shows the result of a single layer board without an internal ground plane. The graphs show that even though there are radiators of substantial area surrounding the package, substantial degredation of thermal performance is evident (Figure 14B shows the layout used for the measurements in Figure 14A). Comparing Figures 13 and 14A shows almost a 2:1 improvement for the strategy involving the external ground plane.

It is clear from Figures 13, 14A and Example 1, that if an application is to use all the device drivers, preparations to assure adequate thermal performance of the system must be taken.

If an extensive external ground plane is unavailable, and only an internal ground plane is available, the thermal performance of the device can still be improved by providing thermal vias to connect the radiators to the internal ground plane. Figure 15 shows a proposed scheme for thermal vias (contact board manufactures for specifics about the thermal performance of their products and possible enhancements).

The thermal resistance for this structure on 1.0 oz. Copper connecting each of the four radiators to an internal ground plane and provide an estimated thermal resistance of approximately 5.0°C/W. The vias used in the estimate had 80 mil diameters, on 100 mil centers and a 1.0 mil copper thickness.

MOTOROLA

# MC34156

*Product Preview*

## 28-Channel Inkjet Driver

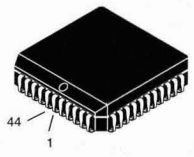
**28–CHANNEL INKJET DRIVER**
**(SMARTMOS™ Technology)**

**SEMICONDUCTOR TECHNICAL DATA**

The MC34156 is a 28–Channel Decoder/Driver intended to be used in inkjet printer applications. By using sophisticated SMARTMOS™ technology, it has been possible to combine low power CMOS inputs and logic and high current, high voltage bipolar outputs capable of sustaining a maximum of 30 V.

A 4–to–14 line decoder determines the selected output driver (n) in each 14–driver bank. Two independent output enable inputs (active low) then provide the final decoding to activate 1– or 2–of–28 outputs ($OUT_{An}$ and/or $OUT_{Bn}$). The ac electrical characteristics of the drivers are tightly controlled and thereby the energy of the device delivers to the inkjet print head. A Chip Enable function is provided to lock out the drivers during system power up. The 28 bipolar power outputs are open collector 30 V Darlington drivers capable of sinking 500 mA at ambient temperatures up to 70°C. All driver outputs are capable of withstanding a contact discharge of ±8.0 kV with the IC biased.

- ESD Output Protection with Clamping Diodes
- Addressable Data Entry
- Tightly Controlled AC and Electrical Characteristics for Inkjet Printers
- CMOS, TTL Compatible Inputs
- Low Power CMOS Logic



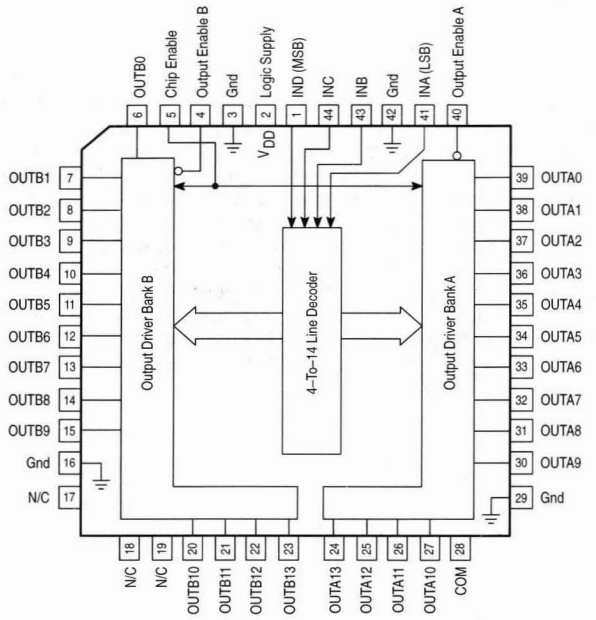

**FN SUFFIX**
PLASTIC PACKAGE
CASE 777

7

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC34156FN | $T_A$ = 0° to +70°C | Plastic Package |

**Simplified Block Diagram**




**PIN ASSIGNMENTS**

| Pin No. | Pin Name | Pin Description |
|---|---|---|
| 1 | IND | 4th Decoder Input |
| 2 | $V_{DD}$ | Power Supply |
| 3 | Gnd | Ground |
| 4 | ENB | Enable Pin for B Set Drivers |
| 5 | Chip Enable | Chip Enable |
| 6 | OUTB0 | B Set 1st Driver |
| 7 | OUTB1 | B Set 2nd Driver |
| 8 | OUTB2 | B Set 3rd Driver |
| 9 | OUTB3 | B Set 4th Driver |
| 10 | OUTB4 | B Set 5th Driver |
| 11 | OUTB5 | B Set 6th Driver |
| 12 | OUTB6 | B Set 7th Driver |
| 13 | OUTB7 | B Set 8th Driver |
| 14 | OUTB8 | B Set 9th Driver |
| 15 | OUTB9 | B Set 10th Driver |
| 16 | Gnd | Ground |
| 17 | N/C | Not Connected |
| 18 | N/C | Not Connected |
| 19 | N/C | Not Connected |
| 20 | OUTB10 | B Set 11th Driver |
| 21 | OUTB11 | B Set 12th Driver |
| 22 | OUTB12 | B Set 13th Driver |
| 23 | OUTB13 | B Set 14th Driver |
| 24 | OUTA13 | A Set 14th Driver |
| 25 | OUTA12 | A Set 13th Driver |
| 26 | OUTA11 | A Set 12th Driver |
| 27 | OUTA10 | A Set 11th Driver |
| 28 | COM | Common |
| 29 | Gnd | Ground |
| 30 | OUTA9 | A Set 10th Driver |
| 31 | OUTA8 | A Set 9th Driver |
| 32 | OUTA7 | A Set 8th Driver |
| 33 | OUTA6 | A Set 7th Driver |
| 34 | OUTA5 | A Set 6th Driver |
| 35 | OUTA4 | A Set 5th Driver |
| 36 | OUTA3 | A Set 4th Driver |
| 37 | OUTA2 | A Set 3rd Driver |
| 38 | OUTA1 | A Set 2nd Driver |
| 39 | OUTA0 | A Set 1st Driver |
| 40 | ENA | Enable Pin for A Set Drivers |
| 41 | INA | 1st Decoder Input |
| 42 | Gnd | Ground |
| 43 | INB | 2nd Decoder Input |
| 44 | INC | 3rd Decoder Input |

**Figure 1. Functional Block Diagram**

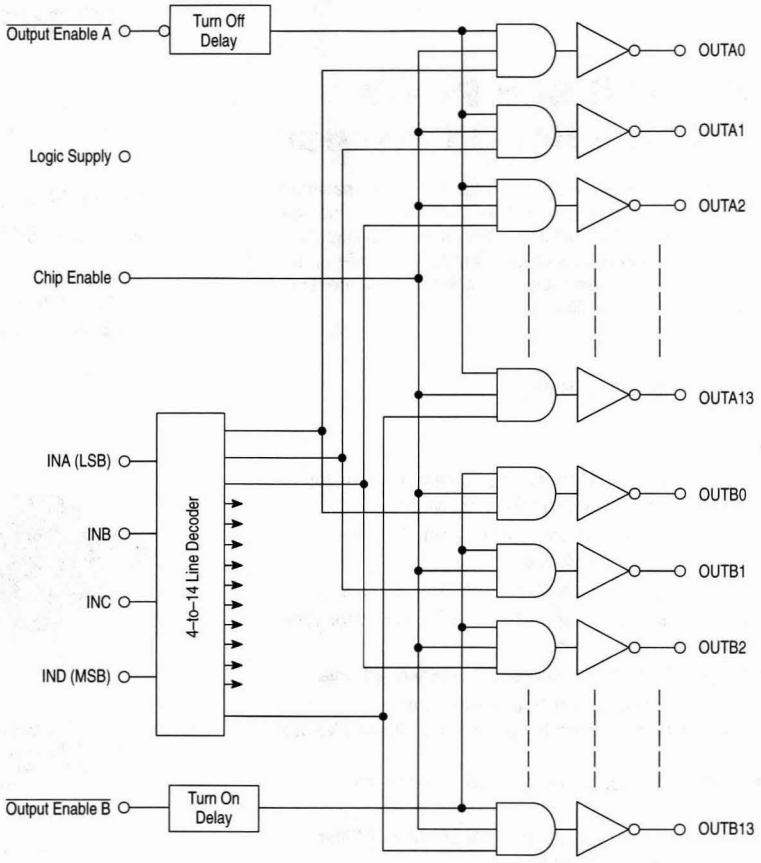



**Figure 2. Output Driver Configuration**

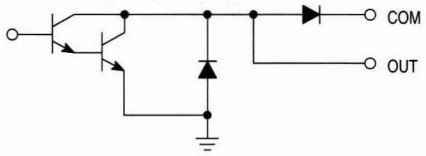
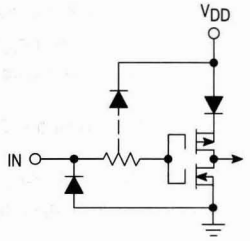



**Figure 3. Typical Input Circuit**

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MOTOROLA

# MC34250

*Product Preview*

## 5.0 V, 200 M-Bit/Sec PR-IV Hard Disk Drive Read Channel

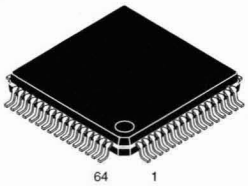
**HARD DISK DRIVE READ CHANNEL**

**SEMICONDUCTOR TECHNICAL DATA**

The Motorola MC34250 is a fully integrated partial response maximum likelihood disk drive read/write channel for use in zoned recording applications. This device integrates the AGC, active filter, 7 tap equalizer, Viterbi detector, frequency synthesizer, servo demodulator, 8/9 rate (0,4/4) Encoder/Decoder with write precompensation and power management in a single 64 pin 10 mm x 10 mm TQFP package.

**FEATURES:**

- 50 to 200 MBPS Programmable Data Rate
- 800 mW at 200 MBPS and 5.0 V
- Channel Monitor Output
- Programmable AGC Charge Pump Currents with Different Values for Data and Servo Envelope Modes and Gain Gradient Mode
- Programmable AGC Peak Detector Droop Currents with Different Values for Data and Servo Envelope Modes
- Separate AGC Charge Pump Outputs for Data and Servo Modes
- Programmable Dual Threshold Qualifier or Hysteresis Comparator Type Pulse Detector for Servo Data Detection.
- ERD and Polarity Outputs for Servo Timing and Raw Encoded Data
- Integrated 7 pole 0.05° Equiripple Linear Phase Filter with Programmable Bandwidth from 5.0 MHz to 80 MHz and Different Values for Both Data and Servo Modes
- Programmable Symmetrical Boost from 0 to 10 dB and Different Values for Data and Servo Modes
- Programmable Asymmetrical Boost of Up to ±40% of Nominal Filter Group Delay in Both Data and Servo Modes
- 7 Tap Continuous Time Transversal Equalizer with 8 Bit Programmable Tap Weights and Integrated Decision Directed Sign–Sign Least Mean Squared Adaptation
- Internal Offset Cancellation Loops
- Fast Acquisition Data Phase Locked Loop with Zero Phase Restart
- Programmable Data Phase Locked Loop Charge Pump Current
- Integrated Soft Decision Viterbi Detectors with Programmable Merge References
- Integrated 8/9 Rate (0,4/4) Encoder and Decoder with Code Scrambler and Descrambler
- Programmable 2/4/8 Bit NRZ Data Interface
- Programmable Write Precompensation Delays Locked to the Frequency Synthesizer
- Differential PECL Write Data Outputs
- External Write Data Path for DC Erase or Other Non–Encoded Data
- Integrated Write Current DAC
- Programmable Power Management
- Bi–Directional Serial Microprocessor Interface
- Various Test Modes Controlled Via the Serial Microprocessor Interface



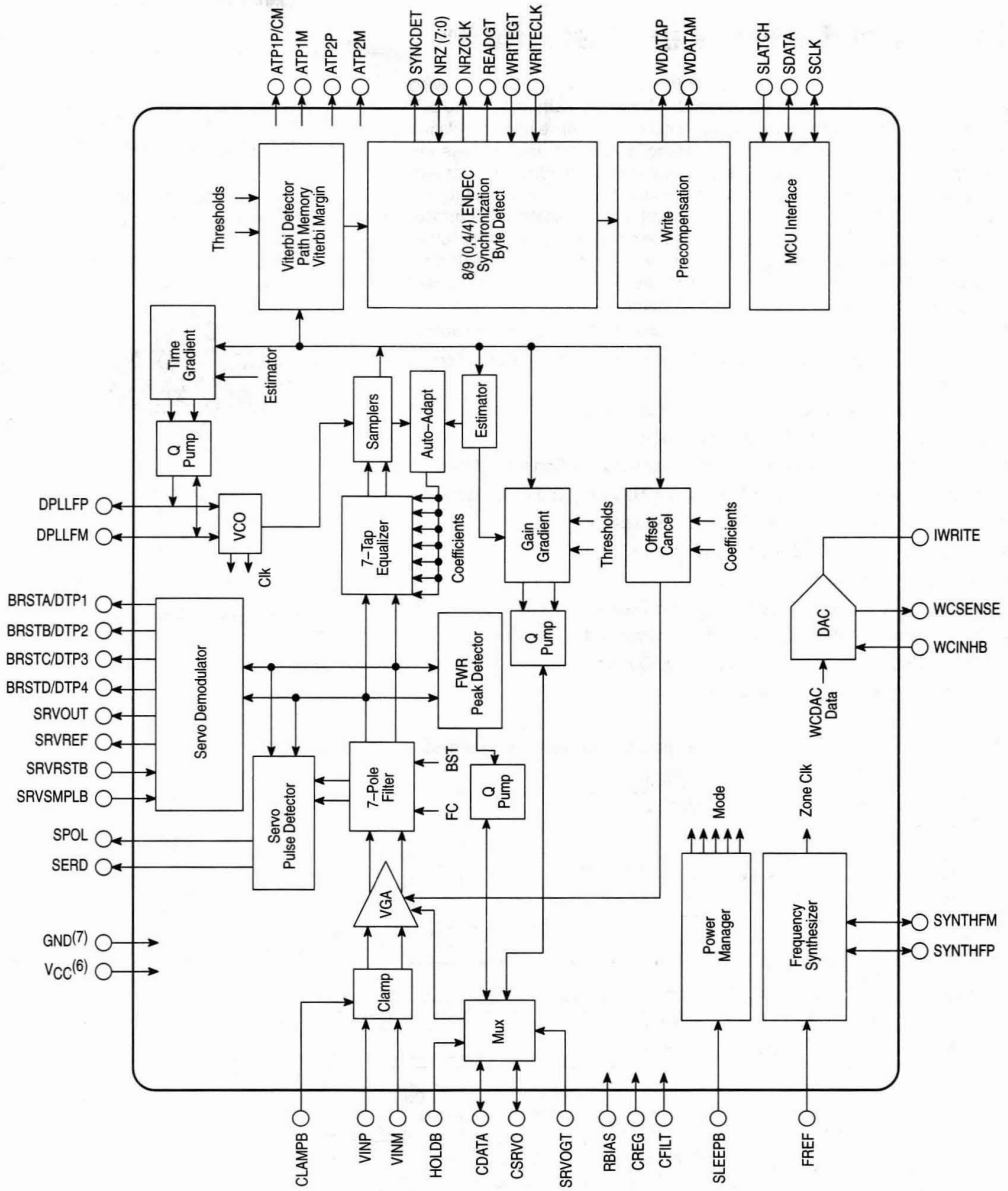

**FTA SUFFIX**
PLASTIC PACKAGE
CASE 840F
(Thin QFP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC34250FTA | $T_A$ = 0° to +70°C | TQFP–64 |

7

## Simplified Block Diagram




This device contains 80,000 active transistors.

7

MOTOROLA

# MC68160

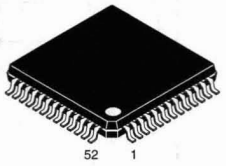
# Enhanced Ethernet Transceiver

**ENHANCED ETHERNET INTERFACE TRANSCEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC68160 Enhanced Ethernet Interface Circuit is a BiCMOS device which supports both IEEE 802.3 Access Unit Interface (AUI) and 10BASE–T Twisted Pair (TP) Interface media connections through external isolation transformers. It encodes NRZ data to Manchester data and supplies the signals which are required for data communication via 10BASE–T or AUI interfaces. The MC68160 gluelessly interfaces to the Ethernet controller contained in the MC68360 Quad Integrated Communications Controller (QUICC) device. The MC68160 also interfaces easily to most other industry–standard IEEE 802.3 LAN controllers. Prior to twisted pair data reception, Smart Squelch circuitry qualifies input signals for correct amplitude, pulse width, and sequence requirements.

- Interfaces with AMD, National, Intel and Fujitsu IEEE 802.3 LAN Controllers
- Automatic Twisted Pair Wiring Polarity Fault Detection and Correction Option
- Automatic Port Selection Option with Status Output
- Driver Pre–emphasis for Twisted Pair Output Data
- Crystal Controlled Clock Oscillator or External Clock Generator Option
- Digital Phase–Locked–Loop (DPLL) Timing Recovery and Data Decoding
- Standby Mode with Reduced Power Consumption
- Twisted Pair Signal Quality Error (Heartbeat) Test Option
- Diagnostic Local Loop Back Option
- Transmit, Receive and Collision Detection Status Output
- Full–Duplex Operation Option on Twisted Pair Port
- Twisted Pair Jabber Detection and Status Output
- Link Integrity Testing and Status Output

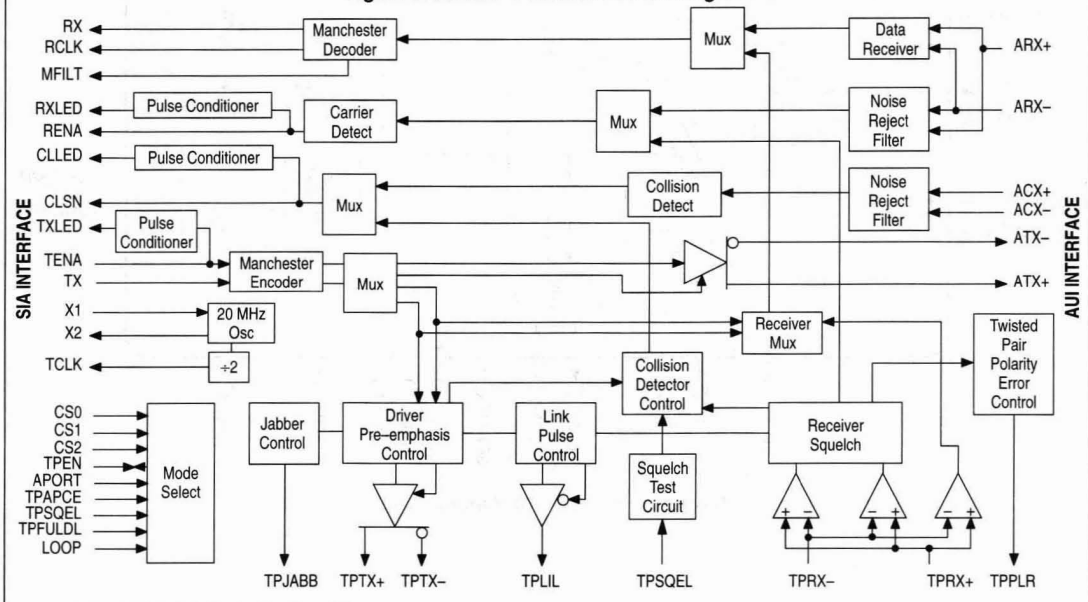



**FB SUFFIX**
PLASTIC PACKAGE
CASE 848D
(Thin QFP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC68160FB | $T_A$ = 0° to + 70°C | TQFP–52 |

**Figure 1. 10Base–T Interface Block Diagram**




This device contains 20,000 active transistors.

# MC68160

## Enhanced Ethernet Serial Transceiver


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**Table 1. Pin Function Description**

| Pin(s) | Symbol | Type | Name/Function |
|---|---|---|---|
| **CONTROLLER INTERFACE** | | | |
| 1 | RENA | O TTL/CMO | **Receive Enable Output:** Indication of the presence of network activity, synchronous to RCLK. In the standby mode, RENA is driven to the high impedance state. |
| 2 | RX | O TTL/CMOS | **Receive Data Output:** Recovered data, synchronous to RCLK. Following a reset operation, 100 ms should be allowed before attempting to read data processed by the MC68160. This delay is needed to insure that the receive phase locked loop is properly synchronized with incoming data. In the standby mode, RX is driven to the high impedance state. |
| 48 | TCLK | O TTL/CMOS | **Transmit Clock Output CMOS/TTL Output:** TCLK provides a symmetrical clock signal at 10 MHz for reference timing of data to be encoded. In the standby mode, TCLK is driven to the high impedance state. |
| 49 | TENA | I TTL | **Transmit Enable Input:** Input signal synchronous to TCLK which enables data transmission on the active port. An internal pull–down resistor is provided so that the input is low under no connect conditions. (This resistor is removed in the standby mode). If TENA is asserted at the conclusion of a reset operation, it must first be deasserted and then reasserted before data transmission can occur. In the standby mode, TENA is driven to the high impedance state. |
| 50 | RCLK | O TTL/CMOS | **Receive Clock Output:** Recovered clock. In the standby mode, RCLK is driven to the high impedance state. |
| 51 | CLSN | O TTL/CMOS | **Collision Output:** In the AUI mode, indicates the presence of signals at the ACX+ and ACX– terminals which meet threshold and pulse width requirements. In the TP mode, indicates simultaneous transmit and receive activity, a heartbeat (SQE Test) signal was generated, or the jabber timer has expired. In the standby mode, CLSN is driven to the high impedance state. |
| 52 | TX | I TTL | **Transmit Data Input:** Input signal synchronous to TCLK which provides NRZ serial data to be Manchester encoded. In the standby mode, TX is driven to the high impedance state. |
| **AUI INTERFACE** | | | |
| 21<br>22 | ACX–<br>ACX+ | I | **AUI Differential Collision Inputs:** These inputs are connected to a pair of internally biased line receivers consisting of a carrier detect receiver with offset threshold and noise filtering to detect the line activity. Signals at ACX+/– have no effect on data path functions. |
| 23<br>24 | ARX–<br>ARX+ | I | **AUI Differential Receiver Inputs:** These inputs are connected to a pair of internally biased line receivers consisting of a carrier detect receiver with offset threshold and noise filtering to detect the line activity, and a data receiver with no offset for Manchester Data reception. |
| 25<br>26 | ATX–<br>ATX+ | O | **AUI Differential Transmit Outputs :** This line pair is intended to operate into terminated transmission lines. For TX signals meeting setup and hold time to TCLK when TENA is previously asserted, Manchester encoded data is outputted at ATX+/–. When operating into a 78 Ω terminated transmission line, signaling meets the required output levels and skew for IEEE–802.3 drop cables. When the 10BASE–T port is automatically or manually selected, the AUI outputs are driven to a low power standby state in which the outputs deliver a balanced high state voltage. |
| **TWISTED PAIR INTERFACE** | | | |
| 31<br>32 | TPRX–<br>TPRX+ | I | **Twisted Pair Differential Receiver Inputs:** These inputs are connected to a receiver with Smart Squelch capability which only allows differential receive data to pass as long as the input amplitude is greater than a minimum signal threshold level and a specific pulse sequence is received. This assures a good signal to noise ratio while the signal pair is active by preventing crosstalk and impulse noise conditions from activating the receive function. |
| 36<br>37 | TPTX–<br>TPTX+ | O | **Twisted Pair Differential Transmitter Outputs:** These lines have pre–distortion drive capability and are intended to drive terminated twisted pair transmission lines. When the AUI port is manually selected, the 10BASE–T outputs are driven to a low power standby state in which the outputs deliver a balanced high state voltage. However, when the AUI port is automatically selected, the 10BASE–T outputs remain active. |

**NOTE:** The sense of the controller interface pins will change, depending on the controller selected.

**Table 1. Pin Function Description (continued)**

| Pin(s) | Symbol | Type | Name/Function |
|---|---|---|---|
| **OSCILLATOR AND FREQUENCY MULTIPLIER** | | | |
| 12 | MFILT | C | **Frequency Multiplier Filter Connection Point:** An external resistor capacitor filter must be attached to this pin. |
| 16 | X1 | I/C CMOS | **Oscillator Inverter Input and Crystal Connection Point:** When connected for crystal oscillator operation, the frequency of the clock which appears at TCLK is half that of the crystal oscillator. As an option, instead of connecting to a crystal, X1 may be driven from an external 20 MHz CMOS compatible clock generator. |
| 17 | X2 | O/C CMOS | **Oscillator Inverter Output and Crystal Connection Point:** This pin is used only for the connection of an external crystal and capacitor. It must be left unconnected if X1 is driven by an external CMOS Clock generator. |
| **MODE SELECT** | | | |
| 3<br>4<br>5 | CS0<br>CS1<br>CS2 | I<br>TTL | **Mode Select:** The logic states applied to these pins select the appropriate interface for the desired IEEE–802.3 controller or enable the standby mode. When the standby mode is selected, the MC68160 power supply current is greatly reduced. Additionally, in the standby mode, all of the controller inputs and outputs are driven to the high impedance state. |
| 6 | LOOP | I<br>TTL | **Diagnostic Loopback:** Asserting this function causes serial NRZ data at the TX input to be Manchester encoded and then looped back through the Manchester decoder, appearing at the RX output. This diagnostic loopback function operates independent of Twisted Pair (TP) or Access Unit Interface (AUI) port connectivity or activity. Neither the TP port nor the AUI port transmits data from the controller while diagnostic loopback is selected. Likewise, the controller interface receives data neither from the TP nor the AUI receivers while in this mode. The polarity fault detection and link integrity functions are not inhibited by the diagnostic loopback mode. If otherwise enabled, they continue to function. If the twisted pair port is selected, and TPSQEL is driven to the low logic state, a collision detect pulse is delivered following each transmission to simulate the twisted pair SQE test. |
| 9 | APORT | I<br>TTL | **Automatic Port Selection Enable:** When high, MC68160 will automatically select the TP or AUI port based on the presence or absence of valid link beats or frames at the TP receive input. If the AUI port is automatically selected, the MC68160 will continue to produce link pulses for the TP port. Changing ports requires approximately 1.0 ms to allow the circuitry for the new port to resume normal operation. The power consumption is minimized in the circuitry associated with the unselected port. |
| 27 | TPSQEL | I<br>TTL | **Twisted Pair Signal Quality Error Test Enable:** Forcing this pin low enables testing of the internal TP collision detect circuitry after each transmit operation to the TP media. This function provides a simulated collision to as much of the MC68160 collision detect circuitry as possible without affecting the attached twisted pair channel. A normal SQE test results in a high logic state at the CLSN controller interface pin which begins 6 to 16–bit times after the last transition of a transmitted signal and continues for 5 to 15–bit times. (When the AUI port is selected, SQE test signals are generated by the coaxial cable transceiver and delivered to the controller via the MC68160 ACX+/– receive inputs) |
| 28 | TPFULDL | I<br>TTL | **Twisted Pair Full Duplex Mode Select:** Forcing this pin low allows simultaneous transmit and receive operation on the twisted pair port without an indicated collision. This pin is not to be asserted with LOOP as a test mode is enabled that disrupts normal operation. |
| 29 | TPAPCE | I<br>TTL | **Twisted Pair Automatic Polarity Correction Enable:** When TPAPCE is high, automatic polarity correction is enabled, and MC68160 will internally correct for a polarity fault on the receive circuit. Additionally, when TPAPCE is high, the presence of a polarity fault is indicated on TPPLR. |
| 46 | TPEN | I/O<br>TTL<br>(TTL/CMOS) | **Twisted Pair Port Enable:** If APORT is low, TPEN is an input which determines whether the AUI port (TPEN low) or TP port (TPEN high) will be manually selected. If the AUI port is manually selected, the MC68160 will not produce link pulses for the TP port.<br><br>If APORT is high, TPEN is an output which will indicate which port has been automatically selected by driving TPEN low (for AUI) or high (for TP). In its output mode TPEN can sink 10 mA in the low output state and source 10 mA in the high output state. (See Pin 9 Description.)<br><br>Changing ports requires approximately 1.0 ms to allow the circuitry for the new port to resume normal operation. The power consumption is minimized in the circuitry associated with the unselected port. In the standby mode, this pin is driven to the high impedance state. |

**Table 1. Pin Function Description (continued)**

| Pin(s) | Symbol | Type | Name/Function |
|---|---|---|---|
| **STATUS INDICATOR** | | | |
| 40 | TXLED | O TTL/CMOS | **Transmit Status LED Driver Output:** This pin indicates the transmit status of the currently selected TP or AUI port. When there is no transmit activity detected, an internal pull–up takes this pin to its normal off (high) state. When transmit activity is detected, the LED driver turns on. In its on state, TXLED flashes the LED by driving low at approximately 10 Hz at a 50% duty cycle. In the standby mode, this output is driven to the high impedance state. |
| 41 | RXLED | O TTL/CMOS | **Receive Status LED Driver Output:** This pin indicates the receive status of the currently selected TP or AUI port. When there is no receive activity detected, an internal pull–up takes this pin to its normal off (high) state. When receive activity is detected, the LED driver turns on. In its on state, RXLED flashes the LED by driving low at approximately 10 Hz at a 50% duty cycle. In the standby mode, this output is driven to the high impedance state. |
| 42 | CLLED | O TTL/CMOS | **Collision Status LED Driver Output:** This pin indicates the collision status of the currently selected TP or AUI port. When there is no collision activity detected, an internal pull–up takes this pin to its normal off (high) state. When collision activity is detected, the LED driver turns on. In its on state, CLLED flashes the LED by driving low at approximately 10 Hz at a 50% duty cycle. In the standby mode, this output is driven to the high impedance state. |
| 43 | TPLIL | O TTL/CMOS | **Twisted Pair Link Integrity Output:** This output is driven to the low output state to indicate good link integrity on the TP port during TP mode. It is deasserted (high) when link integrity fails in TP mode. The TPLIL output is driven to the high impedance state when the AUI port is selected. In the standby mode, this output is also driven to the high impedance state. |
| 44 | TPPLR | O TTL/CMOS | **Twisted Pair Polarity Error Output:** If TPAPCE is high and the wires connected to the Twisted Pair Receiver Inputs (TPRX+, TPRX–) are reversed, TPPLR will be driven to the low logic state to indicate the fault. TPPLR remains low when the MC68160 has automatically corrected for the reversed wires. If the twisted pair link integrity tests fail, this output will be driven to the high logic state. When the AUI mode is selected this output is driven to the high impedance state. In the standby mode, this output is also driven to the high impedance state. |
| 45 | TPJABB | O TTL/CMOS | **Twisted Pair Jabber Output:** This pin is driven high to indicate a jabber condition at the TPTX+/– outputs. (Jabber condition also causes CLLED to be driven alternately to the high and low output levels). TPJABB is driven to the low output state when no jabber condition is present. When the AUI mode is selected this output is driven to the high impedance state. In the standby mode, this output is also driven to the high impedance state. |
| **POWER SUPPLY AND GROUND** | | | |
| 10 | VDDDIV | | **Frequency Divider Supply Pin** |
| 11<br>13 | VDDFM<br>GNDFM | | **Frequency Multiplier Supply and Ground Pins** |
| 14<br>15 | GNDVCO<br>VDDVCO | | **Voltage Controlled Oscillator Ground and Supply Pins** |
| 20 | GNDSUB | | **Substrate Ground Pin** |
| 7<br>8<br>18<br>19 | VDDDIG<br>GNDDIG<br>VDDDIG<br>GNDDIG | | **Digital Supply and Ground Pins** |
| 30<br>33 | VDDANA<br>GNDANA | | **Analog Supply and Ground Pins** |
| 34<br>35<br>38<br>39 | GNDPWR<br>VDDPWR<br>VDDPWR<br>GNDPWR | | **Power Supply and Ground Pins** |
| 47 | GNDCTL | | **Controller Interface Ground Pin** |

**NOTE:** Power and ground pins are not connected internally. Failure to connect externally may cause malfunction or damage to the IC.

**Table 2. Controller Interface Selection**

| Motorola Transceiver MC68160 (EEST™) | Motorola Controller[2] MC68360 (QUICC™) | | Intel Controllers 82586, 82590, 82593, 82596 | | Fujitsu Controllers 86950 (Etherstar™) 86960 (NICE™) | | National Controllers 8390, 83C690, 83932B (SONIC™) | |
|---|---|---|---|---|---|---|---|---|
| CS0<br>CS1<br>CS2 | 1<br>1<br>0 | | 0<br>1<br>0 | | 1<br>0<br>0 | | 0<br>0<br>0 | |
| **Pin** | **Pin** | **Sense** | **Pin** | **Sense** | **Pin** | **Sense** | **Pin** | **Sense** |
| TCLK | TCLK | High | $\overline{\text{TXC}}$ | Low | TCKN | Low | TXC | High |
| TX | TX | High | TXD | High | TXD | High | TXD | High |
| TENA | TENA | High | $\overline{\text{RTS}}$ | Low | TEN | High | TXE | High |
| RCLK | RCLK | High | $\overline{\text{RXC}}$ | Low | RCN | Low | RXC | High |
| RX | RX | High | RXD | High | RXD | High | RXD | High |
| RENA | RENA | High | $\overline{\text{CRS}}$ | Low | XCD | High | CRS | High |
| CLSN | CLSN | High | $\overline{\text{CDT}}$ | Low | XCOL | Low | COL | High |
| LOOP[1] | N.A. | High | $\overline{\text{LPBK}}$ | Low | LBC | High | LPBK | High |

**NOTES:** 1. Although LOOP input is not ordinarily classifed as a controller pin, it is included in this table because its sense varies according to the controller used.
2. The Motorola controller interface contained in the MC68360 (QUICC™) is compatible with the AMD 7990 (LANCE™) and 79C900 (ILACC™) controllers.
3. The pin sense is shown from the perspective of the identified controller pin.

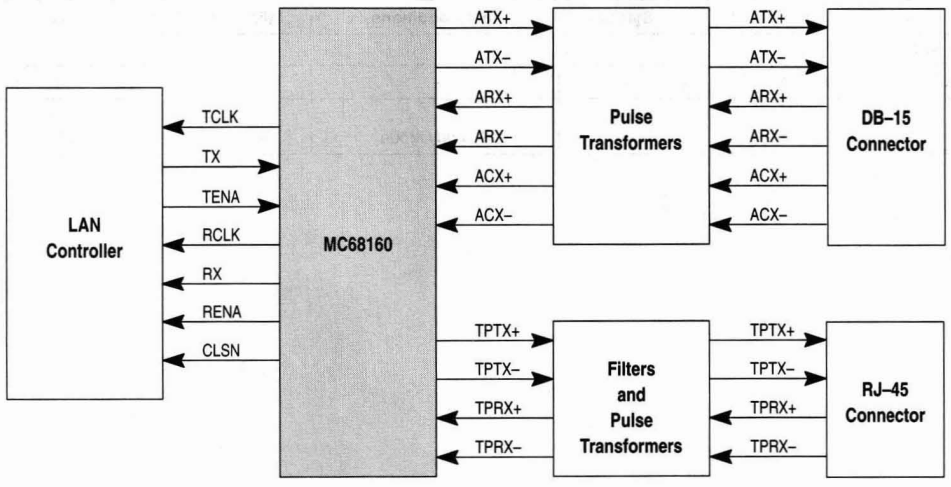
**Table 3. Controller Independent Mode Selection**

| Pin | Standby Mode | Reserved | Reserved | Reserved |
|---|---|---|---|---|
| CS0 | 1 | 0 | 1 | 0 |
| CS1 | 1 | 1 | 0 | 0 |
| CS2 | 1 | 1 | 1 | 1 |

**NOTE:** In standby mode, the MC68160 consumes less power supply current than in any other mode. Additionally, in the standby mode, all of the controller inputs and outputs are driven to the high impedance state. When the standby mode is deasserted, an internal reset pulse of approximately 6.0 µs duration is generated.

Following a period of operation in the standby mode, the time required to insure stable data reception is approximately 100 ms.

**Figure 2. Applications Block Diagram**



## ELECTRICAL CHARACTERISTICS

### MAXIMUM RATINGS

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Storage Temperature Range | $T_{stg}$ | −65 | 150 | °C |
| Power Supply Voltage Range<br>Analog<br>Digital | <br>$V_{DDA}$<br>$V_{DDD}$ | <br>−<br>− | <br>7.0<br>7.0 | V |
| Voltage on any TTL compatible input pin with respect to Ground<br>Voltage on TPRX, ARX, or ACX input pins with respect to Ground | V | −0.5<br>−0.5 | $V_{DD}$ + 0.5<br>6.0 | V |
| Differential Voltage on TPRX, ARX, or ACX Input Pins | $V_{DIFF}$ | −6.0 | 6.0 | V |

**NOTE:** Stresses in excess of the Absolute Maximum Ratings can cause permanent damage to the device. Functional operation of the device is not implied at these or any other conditions in excess of those indicated in the operation sections of this data sheet. Exposure to Absolute Maximum Ratings conditions for extended periods can adversely affect device reliability.

### RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Power Supply Voltage Range | $V_{DD}$ | 4.75 | 5.25 | V |
| Power Supply Ripple (20 kHz to 100 kHz) | – | – | 50 | mV |
| Power Supply Impulse Noise (Either Polarity) | – | – | 100 | mV |
| Ambient Operating Temperature Range | $T_A$ | 0 | 70 | °C |
| ARX/ACX Input Differential Rise and Fall Time (see Figure 39) | $t_{260}$ | 2.0 | 10 | ns |
| ARX Pair Idle Time after Transmission (see Figure 39) | $t_{265}$ | 8.0 | – | µs |

7

### ESD

Although protection circuitry has been designed into this device, proper precautions should be taken to avoid exposure to electrostatic discharge (ESD) during handling and mounting. Motorola employs a Human Body Model (HBM) and a Charged Device Model (CDM) for ESD–susceptibility testing and protection design evaluation. ESD has been adopted for the CDM, however, a standard HBM (resistance = 1500 Ω capacitance – 100 pF) is widely used and, therefore, can be used for comparison purposes. The HBM ESD threshold presented here was obtained by using the circuit parameters contained in this specification. ESD threshold voltage is designed to 1.0 kV Human Body Model.

### DC ELECTRICAL CHARACTERISTICS (Unless otherwise noted, minimum and maximum limits apply over the recommended ambient operating temperature and power supply voltage ranges.)

| Characteristic | Symbol | Test Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | | |
| Undervoltage Shutdown Threshold | – | – | – | – | 4.4 | V |
| Power Supply Current | $I_{DD}$ | –<br>Standby Mode | –<br>– | 145<br>– | 200<br>5.0 | mA |

**DC ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 5.0 V ± 5%. Unless otherwise noted, minimum and maximum limits apply over the recommended ambient operating temperature and power supply voltage ranges.)

| Characteristic | Symbol | Test Conditions | Min | Max | Unit |
|---|---|---|---|---|---|
| **TTL COMPATIBLE INPUTS** | | | | | |
| TTL Compatible Input Voltage | | – | | | V |
| Low State | $V_{IL}$(TTL) | | – | 0.8 | |
| High State | $V_{IH}$(TTL) | | 2.0 | – | |
| Input Current TTL Compatible Input Pins (Note 1) | | 0 V < $V_I$ < $V_{DD}$ | – | ±10 | µA |
| Input Current TENA TTL Compatible Input Pin: with Pull–Down Resistor | | | | | |
| $I_{IH}$ | $I_{IH}$ | | – | +200 | |
| $I_{IL}$ | $I_{IL}$ | | – | –20 | |
| with Pull–Down Resistor removed in Standby Mode | $I_{IH}$ & $I_{IL}$ | | – | ±10 | |
| **CMOS COMPATIBLE INPUTS** | | | | | |
| CMOS Compatible Input Voltage | | – | | | V |
| Low State | $V_{IL}$(CMOS) | | – | 1.0 | |
| High State | $V_{IH}$(CMOS) | | 3.0 | – | |
| Input Current (Pin X1) | $I_{IH}$ & $I_{IL}$ | 0 V < $V_I$ < $V_{DD}$ | – | ±100 | µA |
| **TTL/CMOS COMPATIBLE OUTPUTS** | | | | | |
| TTL/CMOS Compatible Output Voltage | $V_{OL}$ | | | | V |
| Low State (Note 2) | | $I_{OL}$ = 4.0 mA | – | 0.45 | |
| Low State (Note 3) | | $I_{OL}$ = 10 mA | – | 0.45 | |
| TTL/CMOS Compatible Output Voltage | $V_{OH}$ | | | | V |
| High State (Note 4) | | $I_{OH}$ = –500 µA | 3.9 | – | |
| High State (Note 5) | | $I_{OH}$ = –10 mA | 3.9 | – | |
| High State (Note 2) | | $I_{OH}$ = –4.0 mA | 2.4 | – | |
| Three State Output Leakage Current | $I_{OZ}$ | 0 V ≤ $V_{OZ}$ ≤ $V_{DD}$ | – | ±10 | µA |

| Characteristic | Symbol | Test Conditions | Min | Max | Unit |
|---|---|---|---|---|---|
| **TWISTED PAIR RECEIVER INPUTS** | | | | | |
| Input Voltage Range (DC + AC) | $V_{ITP}$ | – | 1.5 | 4.3 | V |
| Differential Input Squelch Threshold Voltage | $V_{ITPSQ}$ | Note 10 | 270 | 390 | mV |
| Common Mode Bias Generator Voltage | $V_{BCMTP}$ | Note 9 | 1.8 | 3.2 | V |
| Common Mode Input Resistance | $R_{CMTP}$ | – | 1000 | – | Ω |
| Differential Input Resistance | $R_{DIFFTP}$ | – | 2.5 | – | kΩ |
| **TWISTED PAIR TRANSMITTER OUTPUTS** | | | | | |
| Differential Output Voltage | | Note 7 | | | V |
| Pre–Emphasis Level | $V_{ODFTPP}$ | | ±2.2 | ±2.8 | |
| Signal Level | $V_{ODFTPS}$ | | ±1.56 | ±1.98 | |
| Common Mode Output Voltage Range | $V_{OCMTP}$ | Note 6 | 0 | 4.0 | V |
| Common Mode Output Voltage in Standby Mode | $V_{OCMTPSB}$ | $I_{OH}$ = –100 µA | $V_{DD}$ – 1.0 | $V_{DD}$ | V |
| Differential Output Voltage | | | | | |
| IDLE Mode | $V_{ODFTPI}$ | Note 6 | – | ±50 | mV |
| Open Circuit | $V_{ODFTPO}$ | Note 8 | – | 5.25 | V |
| Differential Output Impedance | | Note 8 | | | Ω |
| TRANSMISSION Mode | $R_{ODFTPT}$ | | 12 | 28 | |
| IDLE Mode | $R_{ODFTPI}$ | | 8.0 | 29 | |

**NOTES:**
1. APORT, TPAPCE, CS0, CS1, CS2, TX, LOOP, TPFULDL, TPSQEL and TPEN (In Input Mode).
2. TCLK, RX, RCLK, RENA and CLSN.
3. TPPLR, TPLIL, TPJABB, TXLED, RXLED, CLLED and TPEN (In Output Mode).
4. TPPLR, TPLIL, CLLED, TXLED and RXLED.
5. TPJABB and TPEN (In Output Mode).
6. Measured with Test Load B1 (shown in Figure 3), applied directly to the TPTX+/– pins of the device.
7. Measured differentially with Test Load B2 (shown in Figure 4), applied directly to the TPTX+/– pins of the device.
8. Measured directly on the TPTX+/– pins of the device.
9. Measured with Test Load B3 (shown in Figure 5), applied directly to the TPRX+/– pins of the device.
10. The Common Mode Input Voltage is between 1.8 V and 3.2 V.

| Characteristic | Symbol | Test Conditions | Min | Max | Unit |
|---|---|---|---|---|---|
| **TWISTED PAIR TRANSMITTER OUTPUTS** | | | | | |
| Common Mode Output Impedance | | Note 8 | | | |
| TRANSMISSION Mode | $R_{OCMTPT}$ | | 3.0 | 7.0 | Ω |
| IDLE Mode | $R_{OCMTPI}$ | | 1.0 | 10 | kΩ |

**NOTES:** 1. APORT, TPAPCE, CS0, CS1, CS2, TX, LOOP, TPFULDL, TPSQEL and TPEN (In Input Mode).
2. TCLK, RX, RCLK, RENA and CLSN.
3. TPPLR, TPLIL, TPJABB, TXLED, RXLED, CLLED and TPEN (In Output Mode).
4. TPPLR, TPLIL, CLLED, TXLED and RXLED.
5. TPJABB and TPEN (In Output Mode).
6. Measured with Test Load B1 (shown in Figure 3), applied directly to the TPTX+/– pins of the device.
7. Measured differentially with Test Load B2 (shown in Figure 4), applied directly to the TPTX+/– pins of the device.
8. Measured directly on the TPTX+/– pins of the device.
9. Measured with Test Load B3 (shown in Figure 5), applied directly to the TPRX+/– pins of the device.
10. The Common Mode Input Voltage is between 1.8 V and 3.2 V.

**DC ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, minimum and maximum limits apply over the recommended ambient operating temperature and power supply voltage ranges.)

| Characteristic | Symbol | Test Conditions | Min | Max | Unit |
|---|---|---|---|---|---|
| **AUI RECEIVER INPUTS** | | | | | |
| Input Voltage Range (DC + AC) | $V_{IA}$ | – | 1.0 | 4.2 | V |
| Differential Mode Input Voltage Range | $V_{IDFA}$ | – | ±318 | ±1315 | mV |
| Differential Input Squelch Threshold Voltage | $V_{IASQ}$ | – | –275 | –175 | mV |
| Common Mode Input Resistance | $R_{ICMA}$ | 1.0 V < $V_{ICMA}$ < 4.2 V | 1.5 | – | kΩ |
| Differential Input Resistance (ARX, ACX Inputs) | $R_{IDFA}$ | 1.0 V < $V_{ICMA}$ < 4.2 V<br>318 mV < $V_{IDMA}$ < 1315 mV | 5.0 | – | kΩ |
| **AUI TRANSMITTER OUTPUTS** | | | | | |
| Common Mode Output Voltage | | Figure 6 | | | V |
| IDLE Mode | $V_{OCMIA}$ | | 1.0 | 4.2 | |
| ACTIVE Mode | $V_{OCMAA}$ | | 1.0 | 4.2 | |
| STANDBY Mode | $V_{OCMSA}$ | $I_O$ = –100 µA | $V_{DD}$ – 2.0 | $V_{DD}$ – 1.2 | |
| Differential Output Voltage | | Figure 6 | | | mV |
| IDLE Mode | $V_{ODFIA}$ | | – | ±40 | |
| ACTIVE Mode | $V_{ODFAA}$ | | ±600 | ±1315 | |
| Differential Output Load Current | $I_{ODFIA}$ | Figure 7 | | | mA |
| IDLE Mode | | | – | ±4.0 | |
| Output Short Circuit Current | $I_{ODSA}$ | Output Short Circuited to $V_{DD}$ or GND | – | ±150 | mA |

**Figure 3. Test Load B1**

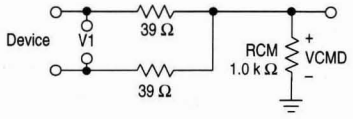



**Figure 4. Test Load B2**

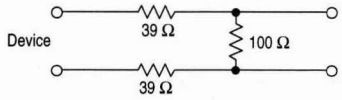
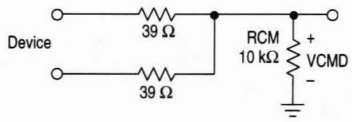



**Figure 5. Test Load B3**




**NOTE:** A total of 50 Ω per driver output is required for proper series line termination. This is realized with the 39 Ω external resistors shown in Figures 3, 4 and 5, together with the internal driver output resistance.

**Figure 6. AUI Common Mode Termination**

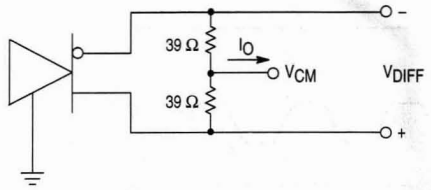
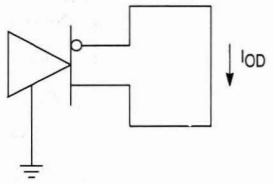



**Figure 7. AUI Differential Output Short Circuit Current**




**AC ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, minimum and maximum limits apply over the recommended temperature and power supply voltage ranges.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **EXTERNAL CLOCK INPUT (X1)** | | | | |
| Cycle Time (Note 1) (See Figure 8) | $t_1$ | 49.995 | 50.005 | ns |
| Fall Time | $t_2$ | – | 5.0 | |
| Rise Time | $t_3$ | – | 5.0 | |
| Low Time | $t_4$ | 20 | 30 | |
| High Time | $t_5$ | 20 | 30 | |
| **RECEIVE PHASE–LOCKED–LOOP SWITCHING** | | | | |
| Stabilization Time | $t_7$ | – | 100 | ms |
| **CONTROLLER TRANSMIT SWITCHING (MOTOROLA MODE)** | | | | |
| TCLK Cycle Time | $t_{10}$ | 99 | 101 | ns |
| TCLK High Time | $t_{11}$ | 45 | 55 | |
| TCLK Low Time | $t_{12}$ | 45 | 55 | |
| TCLK Rise and Fall Time | $t_{13}$ | – | 8.0 | |
| TX Setup Time to TCLK ↑ | $t_{14}$ | 20 | – | ns |
| TX Hold Time to TCLK ↑ | $t_{15}$ | 0 | – | |
| TENA Setup Time to TCLK ↑ | $t_{16}$ | 20 | – | ns |
| TENA Hold Time to TCLK ↑ | $t_{17}$ | 0 | – | |
| **CONTROLLER RECEIVE SWITCHING** | | | | |
| RCLK Cycle Time | $t_{20}$ | 90 | – | ns |
| RCLK High Time | $t_{21}$ | 42 | – | |
| RCLK Low Time | $t_{22}$ | 47 | 55 | |
| RCLK Rise and Fall Time | $t_{23}$ | – | 8.0 | |
| RX Hold Time from RCLK ↑ | $t_{24}$ | 10 | – | ns |
| RX Set–Up Time to RCLK ↑ | $t_{24.1}$ | 70 | – | |
| RCLK Delay from RENA ↑ | $t_{25}$ | – | 650 | ns |
| RX Delay from RENA ↑ | $t_{26}$ | – | 600 | |
| RENA Deassertion Delay from RCLK ↑ (See Figure 12) | $t_{27}$ | 10 | 30 | ns |

**NOTES:** 1. To meet IEEE–802.3 specifications.
2. Load on specified output is 20 pF to ground, unless otherwise noted.
3. ↑ = Rising Edge

**Figure 8. X1 Input Voltage Levels for Timing Measurements**

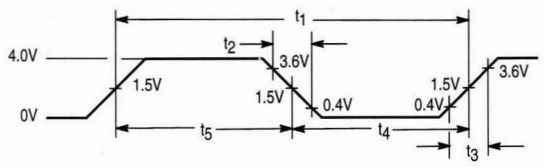
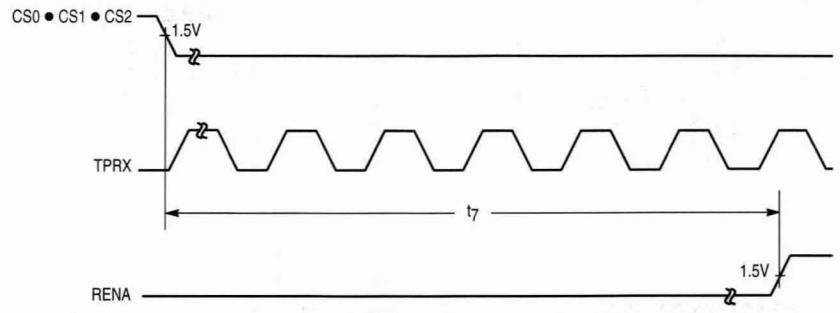


**Figure 9. Receive Phase–Locked–Loop Switching**




**NOTE:** CS0 • CS1 • CS2 is the logical AND operation and refers to the pins not at Logic 1.

**Figure 10. Transmit Timing (Motorola Mode)**

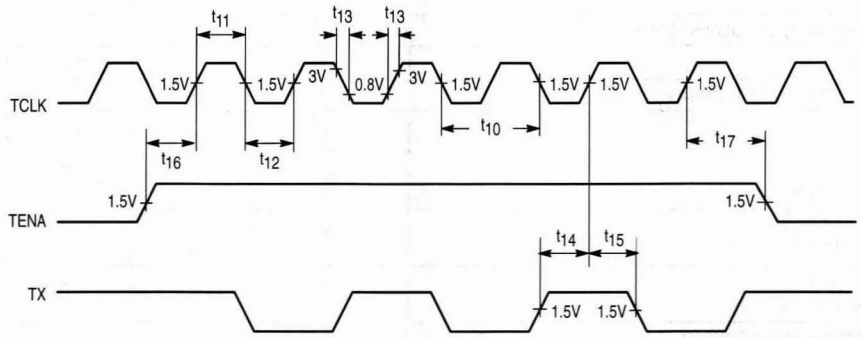



**Figure 11. Receive Timing (Motorola Start of Frame)**

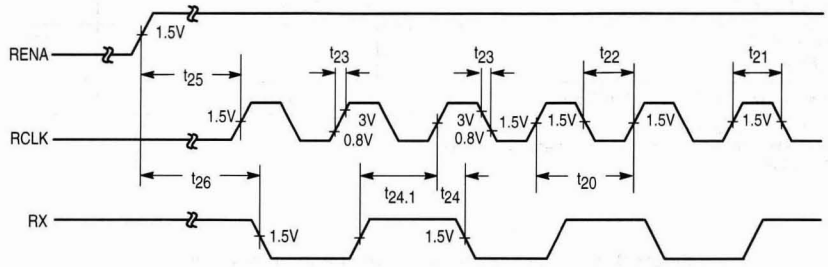
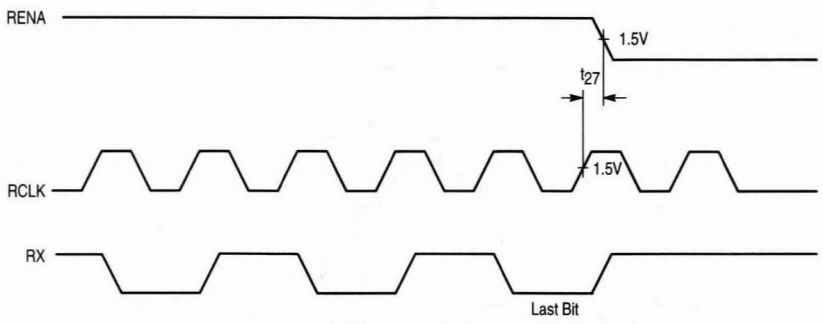


**Figure 12. Receive Timing (Motorola End of Frame)**




**CONTROLLER TRANSMIT SWITCHING (Intel Mode)**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| $\overline{TXC}$ Cycle Time | $t_{40}$ | 99 | 101 | ns |
| $\overline{TXC}$ High and Low Time | $t_{41}$ | 40 | – | |
| $\overline{TXC}$ Rise and Fall Time | $t_{42}$ | – | 5.0 | |
| TXD Setup Time to $\overline{TXC}$ ↓ | $t_{43}$ | 20 | – | ns |
| TXD Hold Time to $\overline{TXC}$ ↓ | $t_{44}$ | 0 | – | |
| $\overline{RTS}$ Setup Time to $\overline{TXC}$ ↓ | $t_{45}$ | 20 | – | ns |
| $\overline{RTS}$ Hold Time to $\overline{TXC}$ ↓ | $t_{46}$ | 0 | – | |

**CONTROLLER RECEIVE SWITCHING**

| | | | | |
|---|---|---|---|---|
| $\overline{RXC}$ Cycle Time | $t_{80}$ | 90 | – | ns |
| $\overline{RXC}$ High Time | $t_{81}$ | 45 | 55 | |
| $\overline{RXC}$ Low Time | $t_{82}$ | 40 | – | |
| $\overline{RXC}$ Rise and Fall Time | $t_{83}$ | – | 5.0 | |
| RXD Hold Time from $\overline{RXC}$ ↓ | $t_{85}$ | 50 | – | ns |
| RXD Set–Up Time to $\overline{RXC}$ ↓ | $t_{85.1}$ | 35 | – | |
| $\overline{CRS}$ Delay from $\overline{RXC}$ ↑ | $t_{86}$ | 12 | 30 | |

**NOTE:** Load on specified output is 20 pF to ground, unless otherwise noted.
↑ = Rising Edge
↓ = Falling Edge

**Figure 13. Transmit Timing (Intel)**

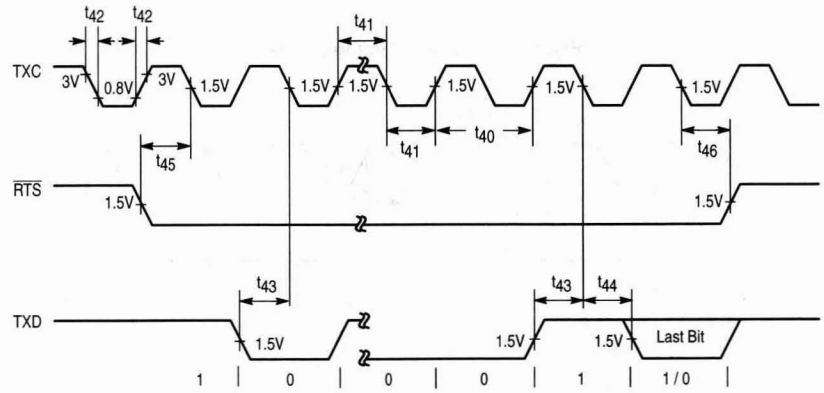
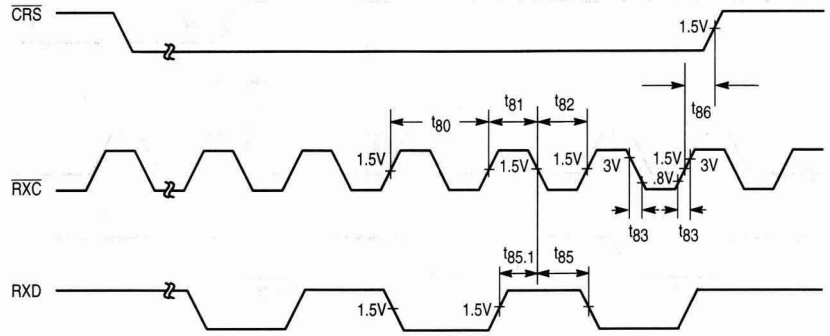


**Figure 14. Receive Timing (Intel)**




**CONTROLLER TRANSMIT SWITCHING (Fujitsu Mode)**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| TCKN Cycle Time<br>TCKN High and Low Time<br>TCKN Rise and Fall Time | $t_{90}$<br>$t_{91}$<br>$t_{92}$ | 99<br>45<br>– | 101<br>55<br>8.0 | ns |
| TXD Setup Time to TCKN ↓<br>TXD Hold Time to TCKN ↓ | $t_{93}$<br>$t_{94}$ | 20<br>0 | –<br>– | ns |
| TEN Setup Time to TCKN ↓<br>TEN Hold Time to TCKN ↓ | $t_{95}$<br>$t_{96}$ | 20<br>0 | –<br>– | ns |
| **CONTROLLER RECEIVE SWITCHING** | | | | |
| RCKN Cycle Time<br>RCKN High Time<br>RCKN Low Time<br>RCKN Rise and Fall Time | $t_{100}$<br>$t_{101}$<br>$t_{102}$<br>$t_{103}$ | 90<br>40<br>45<br>– | –<br>–<br>55<br>8.0 | ns |
| RXD Hold Time from RCKN ↓<br>RXD Set–Up Time RCLK ↓<br>RCKN Delay from XCD ↑ | $t_{104}$<br>$t_{104.1}$<br>$t_{105}$ | 50<br>35<br>– | –<br>–<br>600 | ns |
| XCD Deassertion Delay from RCKN ↑ (See Figure 17) | $t_{106}$ | 0 | – | ns |

**NOTE:** Load on specified output is 20 pF to ground, unless otherwise noted.
↑ = Rising Edge
↓ = Falling Edge

**Figure 15. Transmit Timing (Fujitsu)**

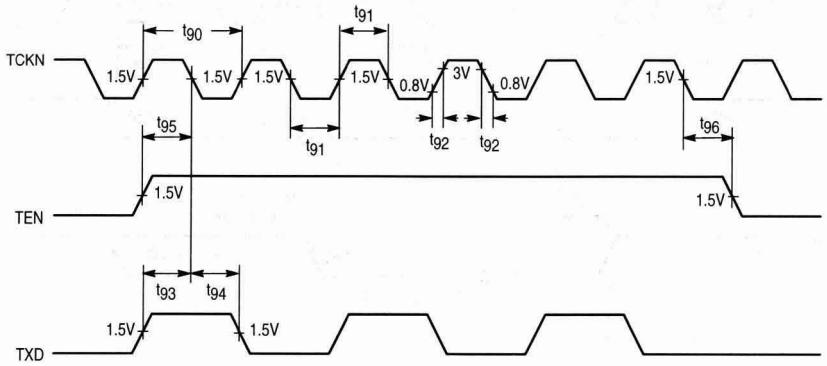


**Figure 16. Receive Timing (Fujitsu Start of Frame)**

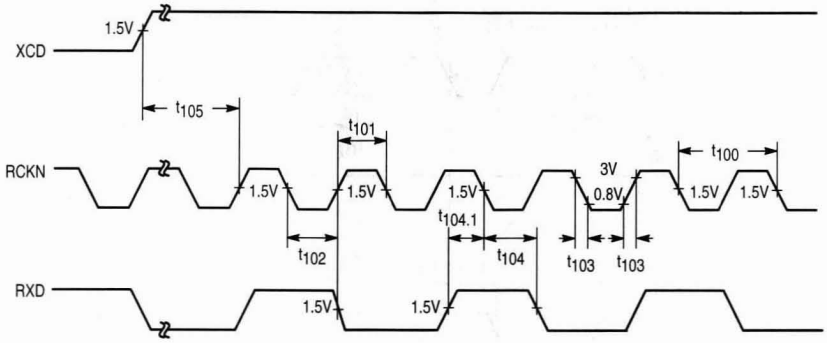
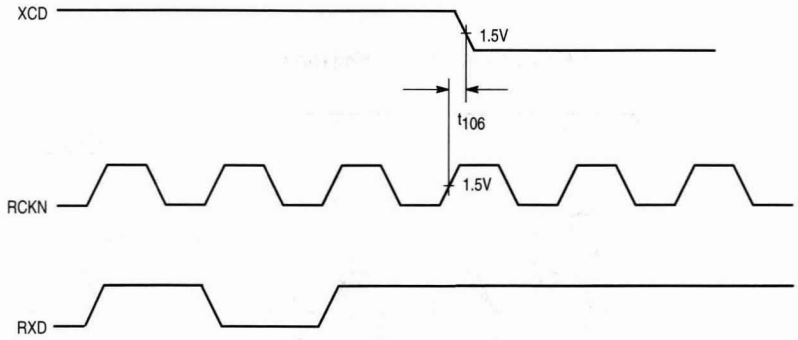



**Figure 17. Receive Timing (Fujitsu End of Frame)**




**CONTROLLER TRANSMIT SWITCHING (National Mode)**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| TXC Cycle Time | $t_{110}$ | 99 | 101 | ns |
| TXC High and Low Time | $t_{111}$ | 45 | 55 | |
| TXC Rise and Fall Time | $t_{112}$ | – | 8.0 | |
| TXD Setup Time to TXC ↑ | $t_{113}$ | 20 | – | ns |
| TXD Hold Time to TXC ↑ | $t_{114}$ | 0 | – | |
| TXE Setup Time to TXC ↑ | $t_{115}$ | 20 | – | ns |
| TXE Hold Time to TXC ↑ | $t_{116}$ | 0 | – | |

**CONTROLLER RECEIVE SWITCHING**

| | | | | |
|---|---|---|---|---|
| RXC Cycle Time | $t_{120}$ | 90 | – | ns |
| RXC Low Time | $t_{121}$ | 40 | – | |
| RXC High Time | $t_{122}$ | 40 | 60 | |
| RXC Rise and Fall Time | $t_{123}$ | – | 8.0 | |
| RXD Hold Time from RXC ↑ | $t_{124}$ | 50 | – | ns |
| RXD Set–Up Time from RXC ↑ | $t_{124.1}$ | 35 | – | |
| RXC Delay from CRS ↑ | $t_{125}$ | – | 600 | |
| CRS Deassertion Delay from RXC ↓ | $t_{126}$ | 0 | 15 | ns |
| RXC continuing beyond CRS ↓ | $t_{127}$ | 5.0 | – | cycles |

**NOTE:** Load on specified output is 20 pF to ground, unless otherwise noted.
↑ = Rising Edge
↓ = Falling Edge

**Figure 18. Transmit Timing (National)**

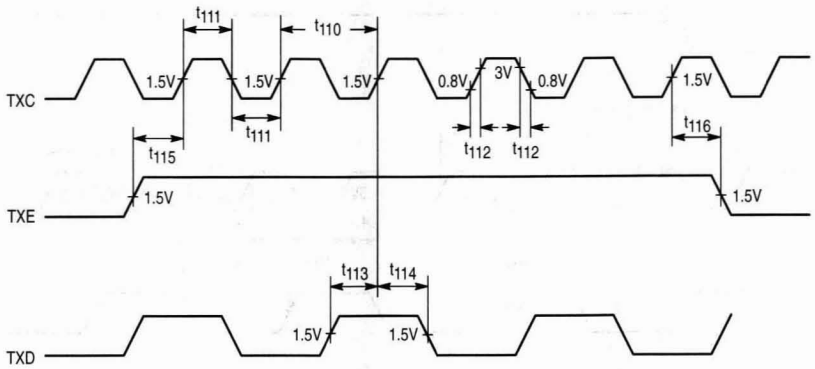
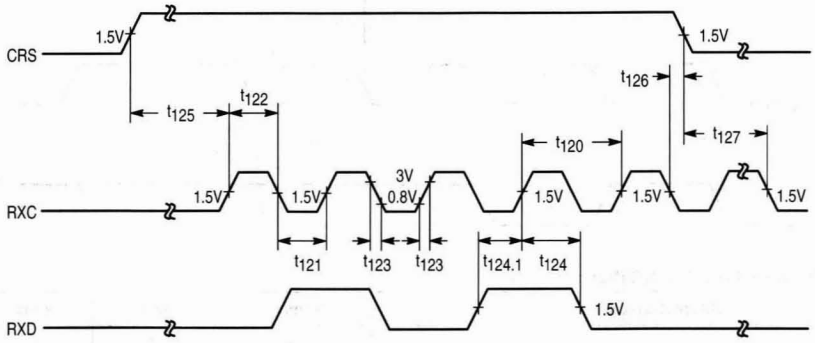



**Figure 19. Receive Timing (National)**




7

**TP TRANSMIT SWITCHING**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| TPTX Common Mode AC Output Voltage (Note 3) | $V_{OCMTP}$ | – | – | 50 | mVrms |
| TX to TPTX Steady State Propagation Delay (Note 2) (See Figure 24)<br>Bit Duration Center–to–Center<br>Half–Bit Cell Duration Center–to–Boundary | $t_{130}$<br>$t_{131}$<br>$t_{132}$ | –<br>98<br>48 | –<br>–<br>– | 200<br>102<br>52 | ns |
| TENA Assert to RENA Assert Delay (Note 7) (See Figure 24) | $t_{133}$ | – | – | 400 | ns |
| Internal Loopback Delay from TX to RX (Note 7) (See Figure 24) | $t_{134}$ | – | – | 450 | ns |
| TPTX End of Packet Hold Time from last positive TPTX Signal Edge to +585 mV Differential Output Level (Note 5) (See Figure 25) | $t_{135}$ | 250 | – | 400 | ns |
| TPTX Precompensation Pulse Width (Notes 2 and 6) (See Figure 25) | $t_{136}$ | – | 45–58 | – | ns |
| RENA Deassert Delay from TENA Deassert when Receiver is inactive<br>Motorola Mode<br>Fujitsu Mode<br>National Mode<br>Intel Mode (Note 4) (See Figure 26) | <br>$t_{137}$<br><br><br>$t_{138}$ | <br>250<br><br><br>250 | <br>–<br><br><br>– | <br>450<br><br><br>450 | ns |
| TPTX Data–to–Link Test Pulse (Note 2) (See Figure 27) | $t_{139}$ | 8.0 | – | 24 | ms |
| TPTX Link Test Pulse Width (Note 2) | $t_{140}$ | 80 | – | 240 | ns |
| TPTX Link Test Pulse Decay–to–Idle Condition (Note 1) | $t_{141}$ | 80 | – | 240 | ns |
| TPTX Link Test Pulse to next Link Test Pulse (Note 2) | $t_{142}$ | 8.0 | – | 24 | ms |

**NOTES:** 1. Measured differentially across the output of Test Load A which is connected directly to the TPTX+/– pins of the device.
2. Measured differentially across the output of Test Load D shown in Figure 23 which is connected directly to the TPTX+/– pins of the device.
3. Measured across the output of Test Load C which is connected directly to the TPTX+/– pins of the device.
4. Same as $t_{137}$ except the logic states for TENA and RENA are inverted.
5. Measured across the output of Test Load B shown in Figure 21.
6. Measured at the +/–90% points of the precompensation voltage feature of the waveform. (The 0% reference is 0 V differential.)
7. Load on specified output is 20 pF to ground.

**Figure 20. Test Load A**

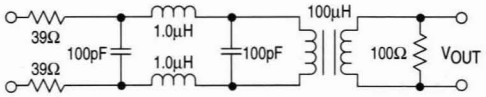



**Figure 21. Test Load B**

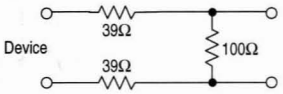



**Figure 22. Test Load C**

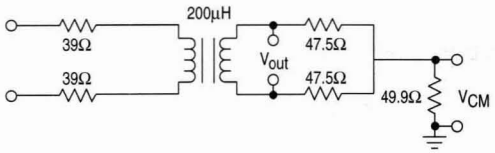
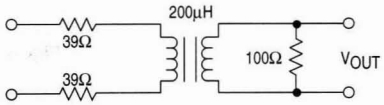



**Figure 23. Test Load D**




**NOTE:** A total of 50 Ω per driver output is required for proper series line termination. This is realized with the 39 Ω external resistors shown in Figures 20 to 23, together with the internal driver output resistance.

**Figure 24. TPTX Transmit Timing (Start of Frame) Switching**

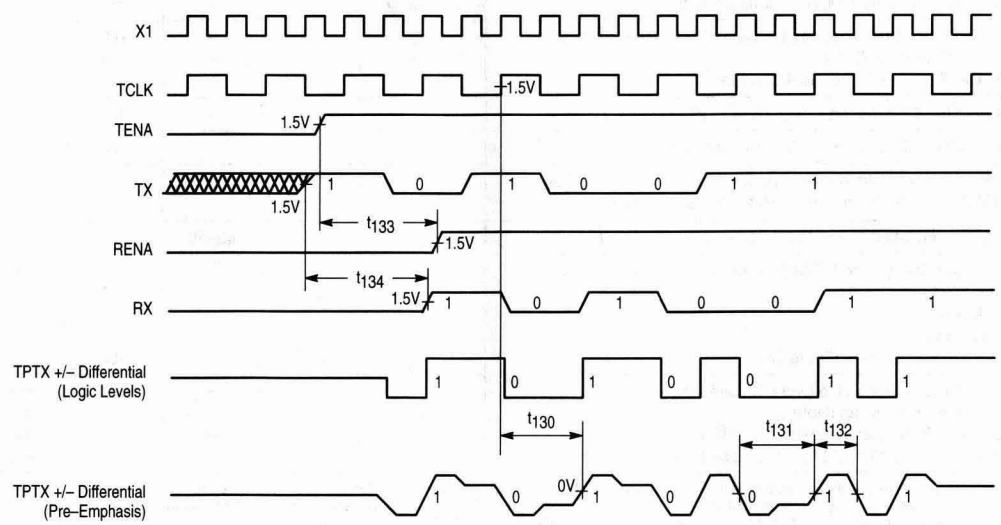



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**Figure 25. TPTX Transmit Timing (End of Frame) Switching**

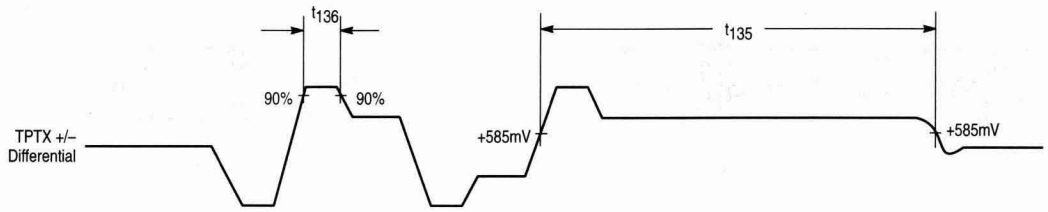



**Figure 26. RENA Deassert Delay from TENA**

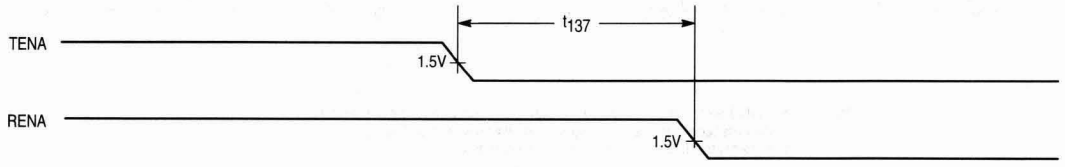
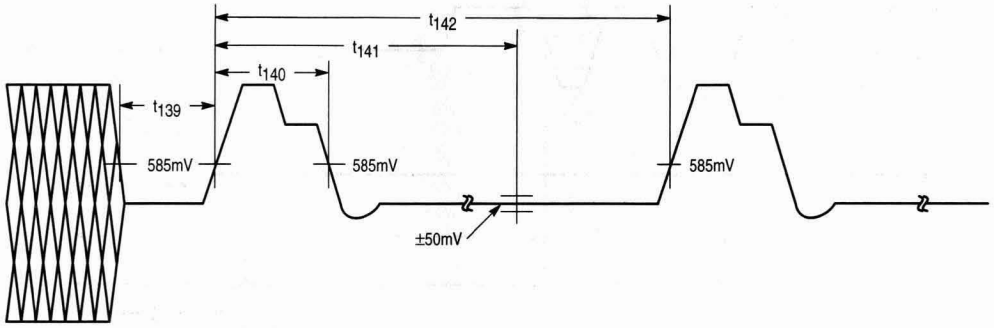


**Figure 27. TPTX+/– Link Pulse Timing**




**TP TRANSMIT JABBER SWITCHING**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Max Length of Transmission before Assertion<br>of TPJABB to indicate Jabber Condition<br>CLSN to indicate Jabber Condition | <br>$t_{160}$<br>$t_{161}$ | <br>20<br>20 | <br>60<br>60 | ms |
| Time from End of Jabber Condition to Deassertion:<br>of TPJABB<br>of CLSN | <br>$t_{162}$<br>$t_{163}$ | <br>500<br>500 | <br>750<br>750 | ms |

**TP TRANSMIT SIGNAL QUALITY ERROR TEST SWITCHING**

| | | | | |
|---|---|---|---|---|
| CLSN (Signal Quality Error Test) (See Figure 29)<br>Assertion from last positive TPTX edge<br>Deassertion from last positive TPTX edge<br>Pulse Width | <br>$t_{170}$<br>$t_{171}$<br>$t_{172}$ | <br>0.6<br>–<br>0.5 | <br>1.6<br>3.1<br>1.5 | µs |
| TPSQEL Disable Delay Time (See Figure 29) | $t_{173}$ | – | 40 | ns |

**NOTE:** The load attached to the specified output is a 20 pF capacitor connected to ground, unless otherwise noted.

**Figure 28. TPJABB Switching**

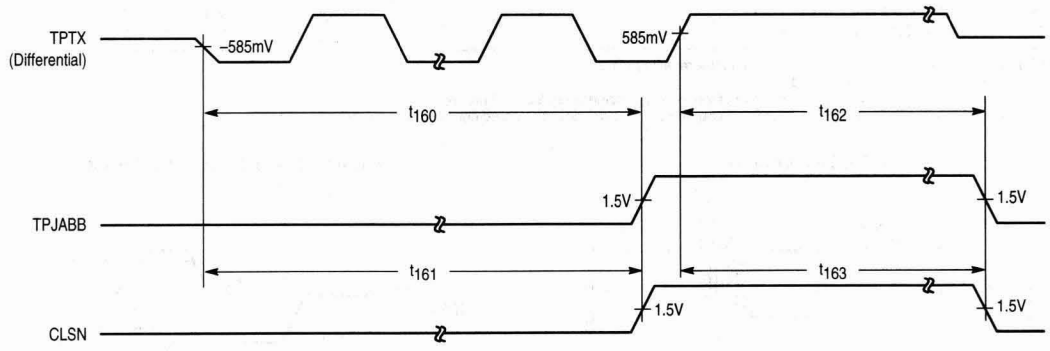
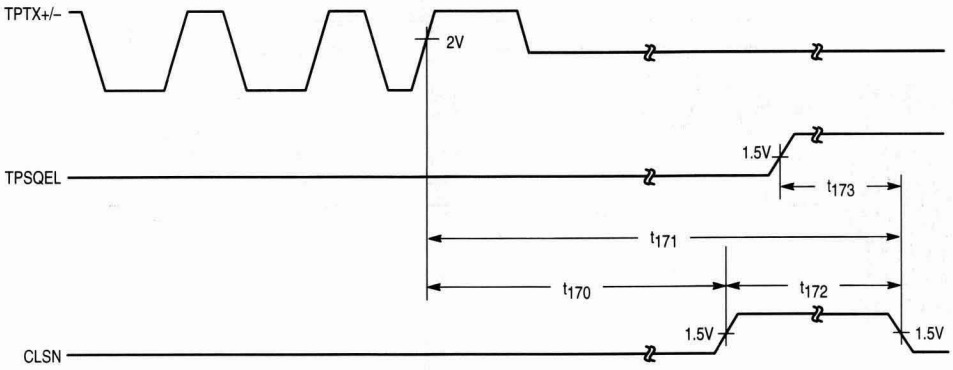


**Figure 29. TPTX SQE (CLSN) Timing (End of Frame)**




**TP RECEIVE SWITCHING**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Differential Input Voltage Range Unconditional Squelch (Note 1)<br>(1.8 V < Input Common Mode Voltage < 3.2 V) | $V_{IDFSTP}$ | 0 | \|264\| | mV |
| Positive or Negative Differential Input Pulse Width for Conditional Receive Unsquelch (See Figure 31) | $t_{180}$ | 20 | 30 | ns |
| TPRX to RCLK Bit Loss at start of packet (See Figure 32) | $t_{181}$ | – | 10 | Bits |
| TPRX to RCLK Steady State Propagation Delay (See Figure 32) | $t_{182}$ | – | 400 | ns |
| TPRX to RX Start Up Delay (See Figure 32) | $t_{183}$ | – | 1.5 | µs |
| TPRX held high from last valid positive transition (See Figure 33) | $t_{186}$ | 230 | – | ns |
| RENA Deassertion Delay from last valid positive transition of TPRX Pair (See Figure 33) | $t_{187}$ | – | 350 | ns |

**TP RECEIVE LINK INTEGRITY SWITCHING**

| | | | | |
|---|---|---|---|---|
| Required Pulse Width Range to be recognized as a Link Pulse (Note 2) | $t_{200}$ | 50 | 200 | ns |
| Last TPRX activity to high state TPLIL Output<br>(Receive Link Loss Timeout Interval) | $t_{201}$ | 100 | 150 | ms |
| Receive Link Beat Separation<br>Minimum Range (Note 3)<br>Maximum Range (Note 4) | <br>$t_{202}$<br>$t_{203}$ | <br>3.0<br>100 | <br>7.0<br>150 | ms |

**NOTES:** 1. Measured with Test Load H attached to the receive pins.
2. Measured at the receive pins.
3. Link beats closer in time to this range of values are considered noise, and are rejected.
4. Link beats further apart in time than this range of values are not considered consecutive, and are rejected.

**Figure 30. Test Load H**

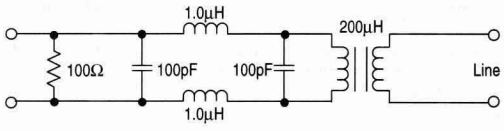



**Figure 31. TPRX Input Switching**

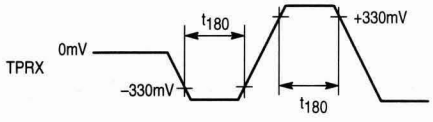


**Figure 32. TPRX Receive Timing (Start of Frame)**

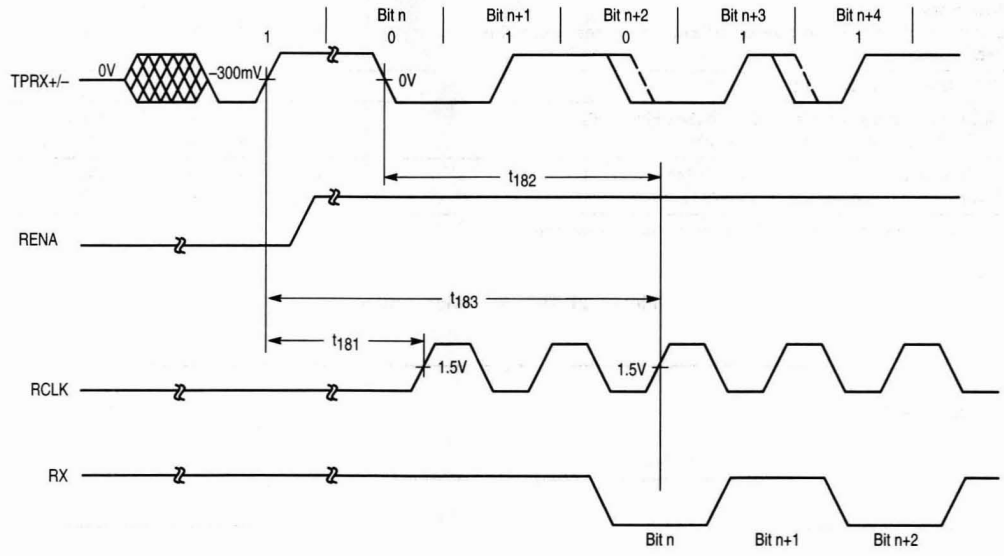



**Figure 33. RENA Deassertion Delay from Last Valid Positive Transition of TPRX Pair**

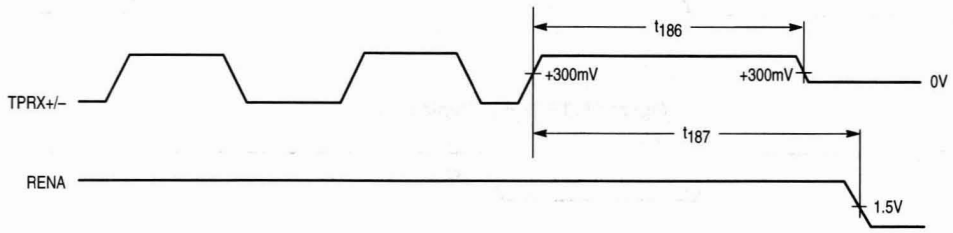
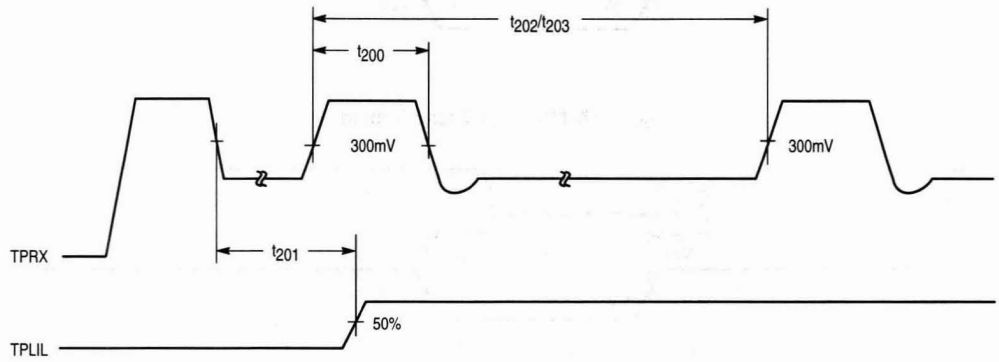



**Figure 34. TP Receive Link Integrity Switching**




7

**TP COLLISION SWITCHING**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Time from collision (TPRX activity caused assertion of RENA followed by assertion of TENA) to assertion of CLSN | $t_{210}$ | – | 300 | ns |
| Time from end of collision (Deassertion of TENA with uninterrupted TPRX pair activity) to deassertion of CLSN | $t_{211}$ | 350 | 900 | |

**TP FULL DUPLEX SWITCHING**

| | | | | |
|---|---|---|---|---|
| TPFULDL assert to collision detect disable (See Figure 36) | $t_{220}$ | – | 50 | ns |
| TPFULDL deassert to collision detect enable | $t_{221}$ | – | 50 | |
| TPFULDL assert to data loop back disable (See Figure 37) | $t_{222}$ | – | 350 | ns |
| TPFULDL deassert to data loop back enable | $t_{223}$ | – | 150 | |

**NOTE:** Load on specified output is 20 pF to ground, unless otherwise noted.

**Figure 35. TPTX Collision Timing**

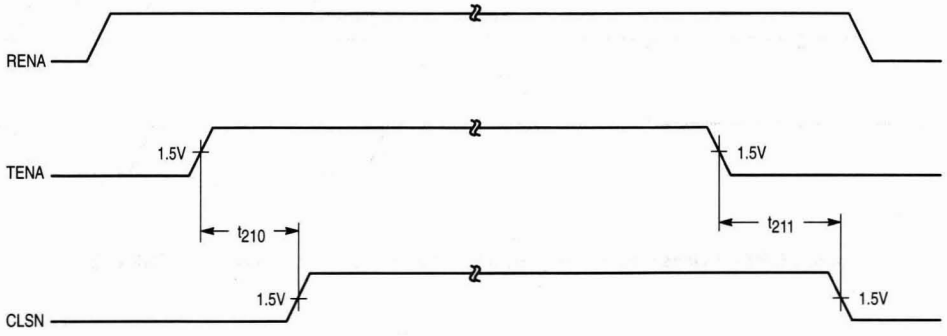



**Figure 36. TPTX Full Duplex Timing**

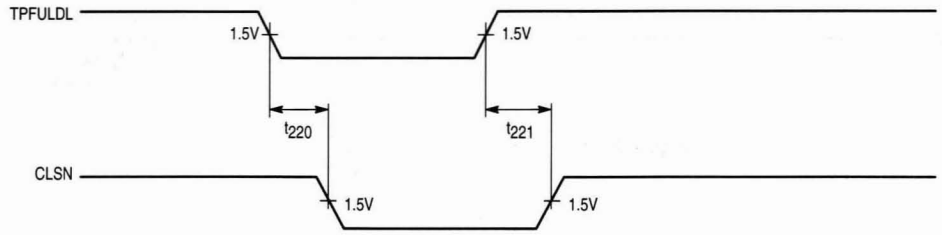
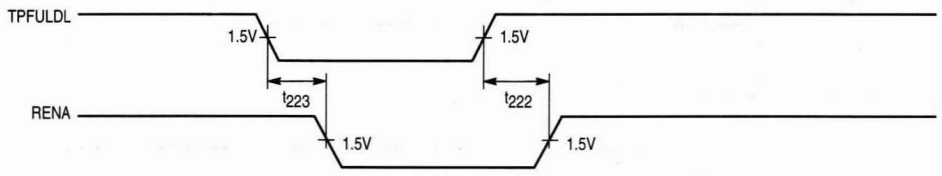



**Figure 37. TPTX Full Duplex Timing**

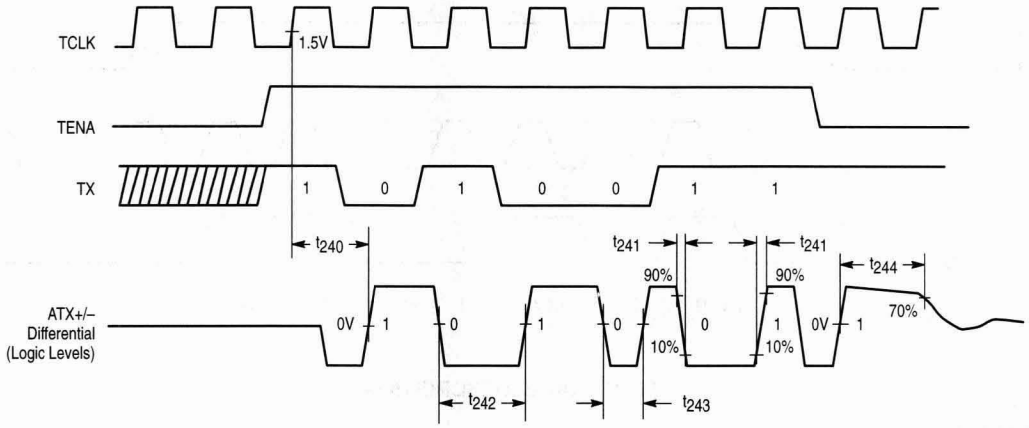


**AUI TRANSMIT SWITCHING**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| TCLK to ATX Pair Steady State Propagation Delay | $t_{240}$ | – | – | 100 | ns |
| Output Differential Rise and Fall Times (Measured directly at device pins) | $t_{241}$ | 1.0 | – | 5.0 | ns |
| ATX Bit Cell Duration center–to–center (Measured directly at device pins) | $t_{242}$ | – | 99.5–100.5 | – | ns |
| ATX Half–Bit Cell Duration center–to–boundary (Measured directly at device pins) | $t_{243}$ | – | 49.5–50.5 | – | ns |
| ATX Pair Held at Positive Differential at start of Idle (Measured through transformer) | $t_{244}$ | 200 | – | – | ns |

**NOTE:** Load on specified output is a shunt 27 μH inductor and 83 Ω resistor.

**Figure 38. ATX Transmit Timings**




**AUI RECEIVE SWITCHING**

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| ARX/ACX Differential Input Voltage Range | – | ±318 | ±1315 | mV |
| ARX/ACX Differential Input Pulse Width to:<br>Initiate Data Reception<br>Inhibit Data Reception | <br>$t_{261}$<br>$t_{262}$ | <br>30<br>– | <br>–<br>18 | ns |
| RENA Assertion Delay<br>RENA Deassertion Delay | $t_{266}$<br>$t_{267}$ | –<br>– | 100<br>450 | ns |

**Squelching Characteristics**
The receive data pairs and the collision pairs should have the following squelch characteristics:
1. The squelch circuits are on at idle (with input voltage at approximately 0 V differential).
2. If an input is in squelch, pulse is rejected if the peak differential voltage is more positive than –175 mV, regardless of pulse width.
3. A pulse is considered valid if its peak differential voltage is more negative than –300 mV and its width, measured at –285 mV, is > 25 ns.
4. The squelch circuits are disabled by the first valid negative differential pulse on either the AUI receive data or collision pair.
5. If a positive differential pulse occurs on either the AUI receive data or collision pair > 175 ns, end of frame is assumed and squelch circuitry is turned on.

**Figure 39. ARX/ACX Timing**

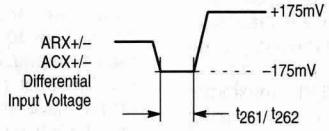
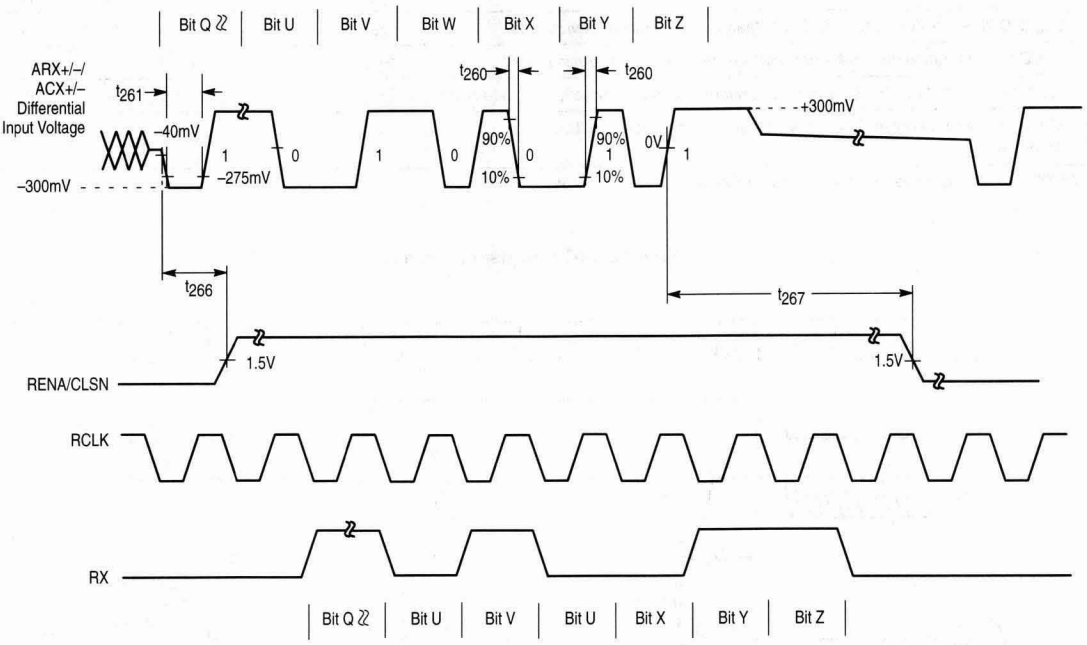


**Figure 40. ARX/ACX Timing**




7

## FUNCTIONAL DESCRIPTION

### Introduction

The MC68160(EEST) was designed to perform the physical connection to the Ethernet media. This is done through two separate media dependent interfaces and a SIA interface. The media dependent interfaces are the Attachment Unit Interface(AUI) and the 10BASE–T Twisted Pair(TP) port. The SIA interface is compatible with most industry controllers and selected by three mode control pins. Chip status is indicated by the condition of 6 status indicator pins. All but one are open collector outputs.

If the EEST isn't receiving data, the controller may initiate transmission. NRZ data from the communications controller SIA interface is encoded by the MC68160 into Manchester Code in preparation for transmission on the media. The data is then applied to either the AUI or TP port. If the data was transmitted using the 10BASE–T port, this data is also looped back to the receive data interface SIA pins connected to the controller. This allows detection of a collision condition in the event that another station on the media attempted transmission at the same time. After the entire data frame has been transmitted, the EEST must force the media idle signal. The idle signal frees the media for other stations that have deferred transmission. If no other transmissions are required the link enters an idle state. During this idle state the 10BASE–T transmitter issues idle pulses which communicates to the receiver connected to the other side that the link is valid. If the transmitter connected at the other end begins transmission, the EEST will assert a receive enable signal, and forward the received data to the controller.

Upon reception of data at the 10BASE–T port, the data is screened for proper sequence and pulse width requirements. If the preamble of the received frame meets the requirements, the PLL locks onto the 64–bit preamble and begins to decode the Manchester Code to NRZ code. This code is then presented to the communications controller at the receive data pins at the SIA interface. If data is received at the AUI port, it is sent directly to the communications controller via the SIA interface.

### Data Transmission

To have properly encoded transmit data, the com–munications controller must be synchronized to TCLK. Transmission to the 10BASE–T or AUI media occurs when TENA is asserted and data is applied to the TX pin. Finally, to signify transmission, the TXLED in will cycle on and off at a 100 ms period. Data transmission for EEST is accomplished either over the 10BASE–T port or the AUI port. Both connections to the media are made with industry standard media interface components. The 10BASE–T interface requires a filter and transformer, the AUI interface requires only a transformer. The filter for the 10BASE–T transmit circuit will have to be chosen for each application.

If after approximately 40 ms after a TP or AUI transmission has begun, the EEST is still transmitting, the TPJABB pin will assert to signify a jabber condition. Also, the CLLED pin will transition high and low alternately with a 100 ms period. The transmit circuitry is, however, unaffected by the jabber condition, so the communications controller has the responsibility of monitoring and stopping transmission.

When transmission is complete, the transmit circuitry will begin the end of transmit and decay to idle responses necessary to meet requirements of the 802.3 standard for the TP and AUI port.

**Data Reception**

Other than the case of being in Loop Back mode, data reception to the RX pin of the EEST is initiated by signaling at the RX+/– or AUI ARX+/– pins. If at the TP port, the data is screened for validity by checking for sequence and pulse width requirements, then passed to the decode and receive circuitry. The RENA pin asserts and the data and corresponding clock is passed to the communications controller. After the frame has been transmitted, the MC68160 detects the ending transmission and negates RENA. If at the AUI port, the data is checked for proper pulse width requirements before being passed to the decode circuitry. If the data pulses are longer than at least 20 ns, RENA gets asserted and the frame is decoded to RX with and accompanying RCLK output.

**Collision**

Collision is the occurrence of simultaneous transmit activity by two or more stations on the network. In the event of collision, the data transfer paths are unaffected. If the MC68160 is in the twisted pair mode, collision is detect by simultaneous receive and transmit activity. If in the AUI mode, collision is detected by activity on the ACX+/– pins. In either case, if collision is detected, the CLSN pin will assert to notify the communications controller.

**Jabber**

The EEST has a jabber timer to detect the jabber condition. In the event that the transmitting station continues to transmit beyond the allowable transmit time, a jabber timer (40 ms) will expire and assert the TPJABB pin to alert the communications controller of the situation. The TPJABB pin can source or sink up to 10 mA, and so, is capable of driving a status LED. In the AUI mode, the pin is driven to high impedance since the transceiver connected to the AUI port must alert the communications controller of the jabber condition.

**Full Duplex**

A feature unique to the MC68160 is the Full Duplex mode. In this mode the EEST is capable of transmitting and receiving simultaneously. Collision conditions are not announced and internal loop back is disabled. The remainder of the EEST functionality remains unchanged from the non–Full Duplex mode. Full Duplex mode is enabled by asserting the TPFULDL pin.

**Auto Port Selection**

If the APORT pin is asserted, the MC68160 will automatically select the TP or AUI port depending on the presence of valid link beats or frames at the TP RX+/– pins. If the AUI port is automatically selected by another transmitting station or by setting TPEN low, the TP transmit port of the EEST continues to transmit link beats to keep the link active.

**Auto Polarity Selection**

If the RX+ and the RX– wires happen to get reversed, the MC68160 has the ability to automatically reverse the pins internally so that the received data is valid. In addition, an open collector status pin (TPPLR) is driven low to indicate the fault. In the AUI or reset mode this pin presents a high impedance.

**Loop Back Mode**

To test the transmit and receive circuitry without disturbing the connected network, the EEST has a Loop Back mode. Loop Back mode routes transmit data and clock to the receive data and clock pins using as much of the transmit and receive circuitry as possible. This gives a test of the MC68160 Manchester encode and decode function.

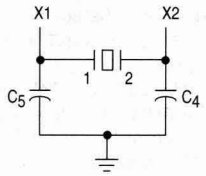
## APPLICATIONS INFORMATION

### Selection of Crystal and External Components

Accuracy of frequency and stability over temperature are the main determinants of crystal choice. Specifications for a suitable crystal are tabulated below.

| | |
|---|---|
| Frequency | 20.000 MHz |
| Mode | Fundamental |
| Tolerance | ± 100 ppm |
| Stability | ± 100 ppm |
| Aging | ± 5 ppm/yr |
| Shunt Capacitance | 7.0 pF |
| Load Capacitance | 18–20 pF |
| Series Fundamental Resistance (ESR) | 25 Ω |
| Drive Level | 500 μW |

A suitable crystal is the MTRON HC49 MP–1, 20.000 MHz crystal. 20 pF for C4 and C5 have been shown to work reliably.




### PLL Filter Components

The filter components at Pin 12 were chosen to assure adequate pull–range but with a emphasis on stability. It is not foreseeable that a design would need to change the components, but for the sake of completeness, relevant values are provided here.

$$\text{VCO Gain} = 24\left(\frac{\text{MHz}}{\text{Volt} \bullet \text{sec}}\right) \text{ and,}$$

$$\text{Phase Detector Gain} = \frac{100}{\pi/2}\left(\frac{\mu\text{A}}{\text{rad}}\right) \text{ and the}$$

filter impedance function is;

$$Z(j\omega) \approx \frac{(j\omega + 1/C6)}{j\omega \bullet C5 \bullet (j\omega + 1/C5)} \text{ (for C6 > > C5)}$$

### 10BASE–T Filter and Transformer Choice

The MC68160 differential outputs are low impedance voltage sources. Therefore, external series resistors must be used in order to match the characteristic impedance of twisted pair. Since the output resistance of each leg of the transmitter is about 10 Ω, a 39 Ω resistor is used in series as shown in the applications schematic. So the impedance presented from the source to the isolation transformer is then very nearly 100 Ω. The following is a list of some 10BASE–T filter module vendors and their products.

| Vendor | Part # |
|---|---|
| FEE Fil–Mag | 78Z1120B–01, 78Z1122B/D–01, 78Z1122 F–01 |
| Valor Electronics | PT3877, FL1012, FL1066 |
| Pulse Engineering | PE–65434, PE65424, PE65433 |
| TOKO | PM01–00, PM02–00, PM05–00 |

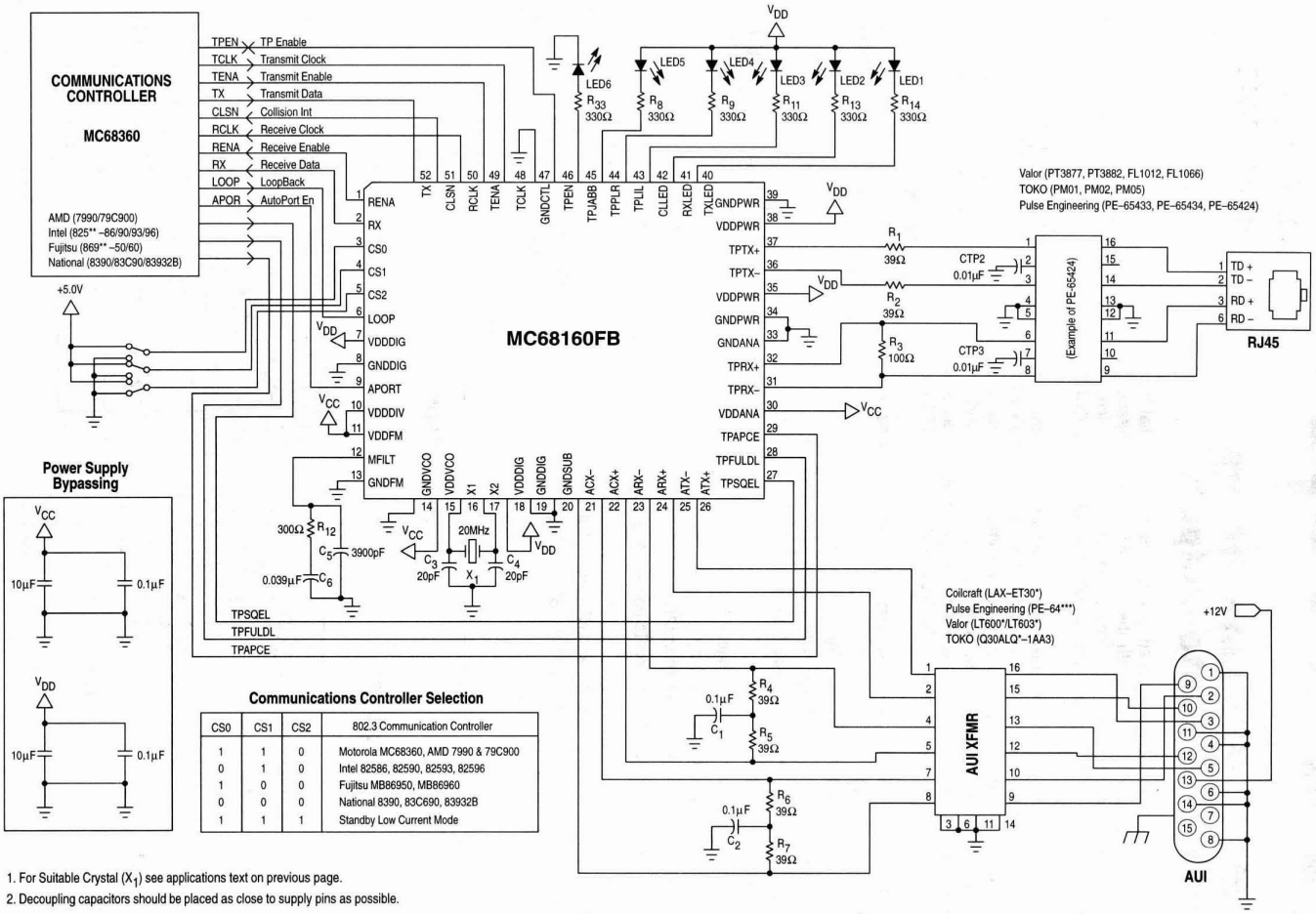
### AUI Transformer Choice

Like the 10BASE–T outputs, the AUI differential outputs are low impedance sources and capable of meeting the IEEE 802.3 waveform requirements when a coupling transformer is used. Some AUI transformer vendors and their products are provided below.

| Vendor | Part # |
|---|---|
| Coilcraft | LAX–ET304 |
| FEE Fil–Mag | 23Z90, 23Z91/ 23Z92 |
| Valor Electronics | LT6032, LT6033 |
| Pulse Engineering | PE64502, PE6103 |
| TOKO | Q30ALQ8–1AA3, Q30ALQ9–1AA3 |

7

**Figure 41. Typical Application Diagram**




1. For Suitable Crystal ($X_1$) see applications text on previous page.
2. Decoupling capacitors should be placed as close to supply pins as possible.

MOTOROLA

# MC75172B
# MC75174B

# Quad EIA-485 Line Drivers with Three-State Outputs

**QUAD EIA–485 LINE DRIVERS**

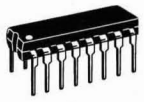
**SEMICONDUCTOR TECHNICAL DATA**

The Motorola MC75172B/174B Quad Line drivers are differential high speed drivers designed to comply with the EIA–485 Standard. Features include three–state outputs, thermal shutdown, and output current limiting in both directions. These devices also comply with EIA–422–A, and CCITT Recommendations V.11 and X.27.

The MC75172B/174B are optimized for balanced multipoint bus transmission at rates in excess of 10 MBPS. The outputs feature wide common mode voltage range, making them suitable for party line applications in noisy environments. The current limit and thermal shutdown features protect the devices from line fault conditions. These devices offer optimum performance when used with the MC75173 and MC75175 line receivers.

Both devices are available in 16–pin plastic DIP and 20–pin wide body surface mount packages.

- Meets EIA–485 Standard for Party Line Operation
- Meets EIA–422–A and CCITT Recommendations V.11 and X.27
- Operating Ambient Temperature: –40°C to +85°C
- High Impedance Outputs
- Common Mode Output Voltage Range: –7 to 12 V
- Positive and Negative Current Limiting
- Transmission Rates in Excess of 10 MBPS
- Thermal Shutdown at 150°C Junction Temperature, (±20°C)
- Single 5.0 V Supply
- Pin Compatible with TI SN75172/4 and NS μA96172/4
- Interchangeable with MC3487 and AM26LS31 for EIA–422–A Applications



**P SUFFIX**
PLASTIC PACKAGE
CASE 648

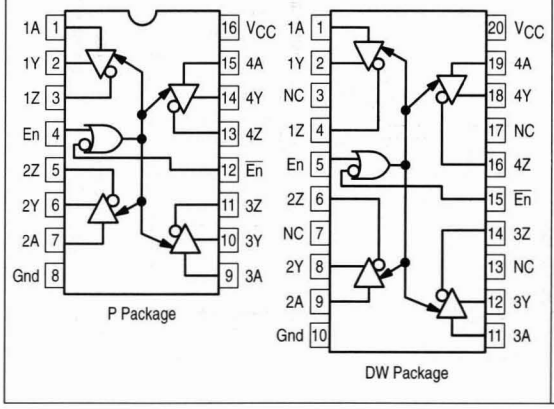
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**ORDERING INFORMATION**

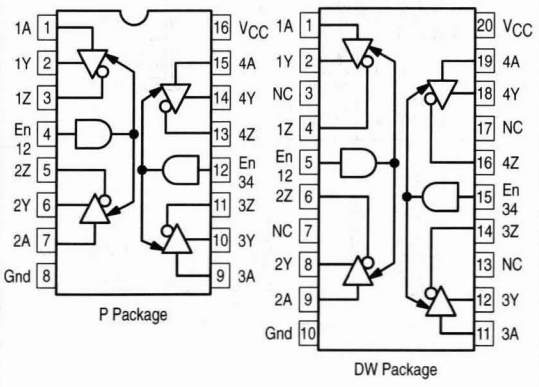
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC75172BDW | $T_A = -40°$ to +85°C | SO–20L |
| MC75174BDW | | SO–20L |
| MC75174BP | | Plastic DIP |

**PIN CONNECTIONS**

**MC75172B**




**MC75174B**



## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | –0.5, +7.0 | Vdc |
| Input Voltage (Data, Enable) | $V_{in}$ | +7.0 | Vdc |
| Input Current (Data, Enable) | $I_{in}$ | –24 | mA |
| Applied Output Voltage, when in 3–State Condition ($V_{CC}$ = 5.0 V) | $V_{za}$ | –10, +14 | Vdc |
| Applied Output Voltage, when $V_{CC}$ = 0 V | $V_{zb}$ | ±14 | |
| Output Current | $I_O$ | Self–Limiting | – |
| Storage Temperature | $T_{stg}$ | –65, +150 | °C |

Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides for actual device operation.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | +4.75 | +5.0 | +5.25 | Vdc |
| Input Voltage (All Inputs) | $V_{in}$ | 0 | – | $V_{CC}$ | Vdc |
| Output Voltage in 3–State Condition, or when $V_{CC}$ = 0 V | $V_{cm}$ | –7.0 | – | +12 | Vdc |
| Output Current (Normal data transmission) | $I_O$ | –65 | – | +65 | mA |
| Operating Ambient Temperature (see text) | $T_A$ | | | | °C |
| EIA–485 | | –40 | – | +85 | |
| EIA–422 | | 0 | – | +85 | |

All limits are not necessarily functional concurrently.

## ELECTRICAL CHARACTERISTICS ($-40°C \leq T_A \leq 85°C$, $4.75\ V \leq V_{CC} \leq 5.25\ V$, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Voltage | | | | | |
| Single–Ended Voltage | | | | | Vdc |
| $I_O$ = 0 | $V_O$ | 0 | – | 6.0 | |
| High @ $I_O$ = –33 mA | $V_{OH}$ | – | 4.0 | – | |
| Low @ $I_O$ = +33 mA | $V_{OL}$ | – | 1.6 | – | |
| Differential Voltage | | | | | |
| Open Circuit ($I_O$ = 0) | $\lvert V_{OD1} \rvert$ | 1.5 | 3.4 | 6.0 | |
| $R_L$ = 54 Ω (Figure 1) | $\lvert V_{OD2} \rvert$ | 1.5 | 2.3 | 5.0 | |
| Change in Differential*, $R_L$ = 54 Ω (Figure 1) | $\lvert \Delta V_{OD2} \rvert$ | – | 5.0 | 200 | mVdc |
| Differential Voltage, $R_L$ = 100 Ω (Figure 1) | $\lvert V_{OD2A} \rvert$ | – | 2.2 | – | Vdc |
| Change in Differential*, $R_L$ = 100 Ω (Figure 1) | $\lvert \Delta V_{OD2A} \rvert$ | – | 5.0 | 200 | mVdc |
| Differential Voltage, $-7.0\ V \leq V_{cm} \leq 12\ V$ (Figure 2) | $\lvert V_{OD3} \rvert$ | 1.5 | – | 5.0 | Vdc |
| Change in Differential*, $-7.0\ V \leq V_{cm} \leq 12\ V$ (Figure 2) | $\lvert \Delta V_{OD3} \rvert$ | – | 5.0 | 200 | mVdc |
| Offset Voltage, $R_L$ = 54 Ω (Figure 1) | $V_{OS}$ | – | 2.9 | – | Vdc |
| Change in Offset*, $R_L$ = 54 Ω (Figure 1) | $\lvert \Delta V_{OS} \rvert$ | – | 5.0 | 200 | mVdc |
| Output Current (Each Output) | | | | | |
| Power Off Leakage, $V_{CC}$ = 0, $-7.0\ V \leq V_O \leq 12\ V$ | $I_{O(off)}$ | –50 | 0 | +50 | µA |
| Leakage in 3–State Mode, $-7.0\ V \leq V_O \leq 12\ V$ | $I_{OZ}$ | –50 | 0 | +50 | |
| Short Circuit Current to Ground | $I_{OSR}$ | –150 | – | +150 | mA |
| Short Circuit Current, $-7.0\ V \leq V_O \leq 12\ V$ | $I_{OS}$ | –250 | – | +250 | |

*$V_{in}$ switched from 0.8 to 2.0 V.
Typical values determined at 25°C ambient and 5.0 V supply.

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**ELECTRICAL CHARACTERISTICS** ($-40°C \leq T_A \leq 85°C$, $4.75\ V \leq V_{CC} \leq 5.25\ V$, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Inputs | | | | | Vdc |
| Low Level Voltage (Pins 4 & 12, MC75174B only) | $V_{IL(A)}$ | 0 | – | 0.7 | |
| Low Level Voltage (All Other Pins) | $V_{IL(B)}$ | 0 | – | 0.8 | |
| High Level Voltage (All Inputs) | $V_{IH}$ | 2.0 | – | $V_{CC}$ | |
| Current @ $V_{in}$ = 2.7 V (All Inputs) | $I_{IH}$ | – | 0.2 | 20 | μA |
| Current @ $V_{in}$ = 0.5 V (All Inputs) | $I_{IL}$ | –100 | –15 | – | |
| Clamp Voltage (All Inputs, $I_{in}$ = –18 mA) | $V_{IK}$ | –1.5 | – | – | Vdc |
| Thermal Shutdown Junction Temperature | $T_{jts}$ | – | +150 | – | °C |
| Power Supply Current (Outputs Open, $V_{CC}$ = 5.25 V) | $I_{CC}$ | | | | mA |
| Outputs Enable | | – | 60 | 70 | |
| Outputs Disabled | | – | 30 | 40 | |

**TIMING CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 5.0 V)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay – Input to Single–ended Output (Figure 3) | | | | | ns |
| Output Low–to–High | $t_{PLH}$ | – | 23 | 30 | |
| Output High–to–Low | $t_{PHL}$ | – | 18 | 30 | |
| Propagation Delay – Input to Differential Output (Figure 4) | | | | | ns |
| Input Low–to–High | $t_{PLH(D)}$ | – | 15 | 25 | |
| Input High–to–Low | $t_{PHL(D)}$ | – | 17 | 25 | |
| Differential Output Transition Time (Figure 4) | $t_{dr}$, $t_{df}$ | – | 19 | 25 | ns |
| Skew Timing | | | | | ns |
| $\lvert t_{PLHD} - t_{PHLD} \rvert$ for Each Driver | $t_{SK1}$ | – | 0.2 | – | |
| Max – Min $t_{PLHD}$ Within a Package | $t_{SK2}$ | – | 1.5 | – | |
| Max – Min $t_{PHLD}$ Within a Package | $t_{SK3}$ | – | 1.5 | – | |
| Enable Timing | | | | | ns |
| Single–ended Outputs (Figure 5) | | | | | |
| Enable to Active High Output | $t_{PZH(E)}$ | – | 48 | 60 | |
| Enable to Active Low Output | $t_{PZL(E)}$ | – | 20 | 30 | |
| Active High to Disable (using Enable) | $t_{PHZ(E)}$ | – | 35 | 45 | |
| Active Low to Disable (using Enable) | $t_{PLZ(E)}$ | – | 30 | 50 | |
| $\overline{\text{Enable}}$ to Active High Output (MC75172B only) | $t_{PZH(E)}$ | – | 58 | 70 | |
| $\overline{\text{Enable}}$ to Active Low Output (MC75172B only) | $t_{PZL(E)}$ | – | 28 | 35 | |
| Active High to Disable (using $\overline{\text{Enable}}$, MC75172B only) | $t_{PHZ(E)}$ | – | 38 | 50 | |
| Active Low to Disable (using $\overline{\text{Enable}}$, MC75172B only) | $t_{PLZ(E)}$ | – | 36 | 50 | |
| Differential Outputs (Figure 6) | | | | | ns |
| $\overline{\text{Enable}}$ to Active Output | $t_{PZD(E)}$ | – | 47 | – | |
| $\overline{\text{Enable}}$ to Active Output (MC75172B only) | $t_{PZD(E)}$ | – | 56 | – | |
| Enable to 3–State Output | $t_{PDZ(E)}$ | – | 32 | – | |
| $\overline{\text{Enable}}$ to 3–State Output (MC75172B only) | $t_{PDZ(E)}$ | – | 40 | – | |

**Figure 1. $V_{DD}$ Measurement**

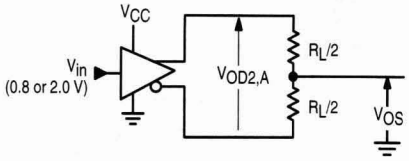



**Figure 2. Common Mode Test**

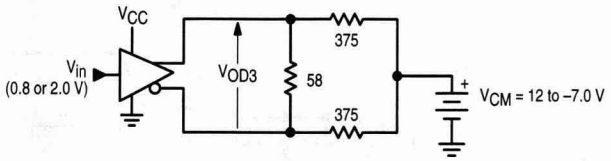



**Figure 3. Propagation Delay, Single–Ended Outputs**

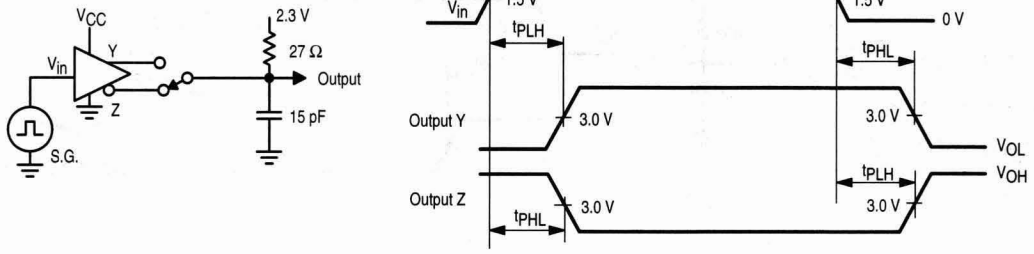
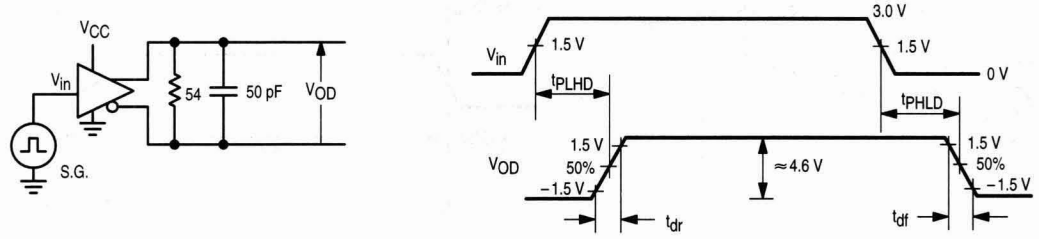



**Figure 4. Propagation Delay, Differential Outputs**




**NOTES:** 1. S.G. set to: f ≤ 1.0 MHz; duty cycle = 50%; $t_r$, $t_f$, ≤ 5.0 ns.
2. $t_{SK1} = |t_{PLHD} - t_{PHLD}|$ for each driver.
3. $t_{SK2}$ computed by subtracting the shortest $t_{PLHD}$ from the longest $t_{PLHD}$ of the 4 drivers within a package.
4. $t_{SK3}$ computed by subtracting the shortest $t_{PHLD}$ from the longest $t_{PHLD}$ of the 4 drivers within a package.

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**Figure 5. Enable Timing, Single–Ended Outputs**

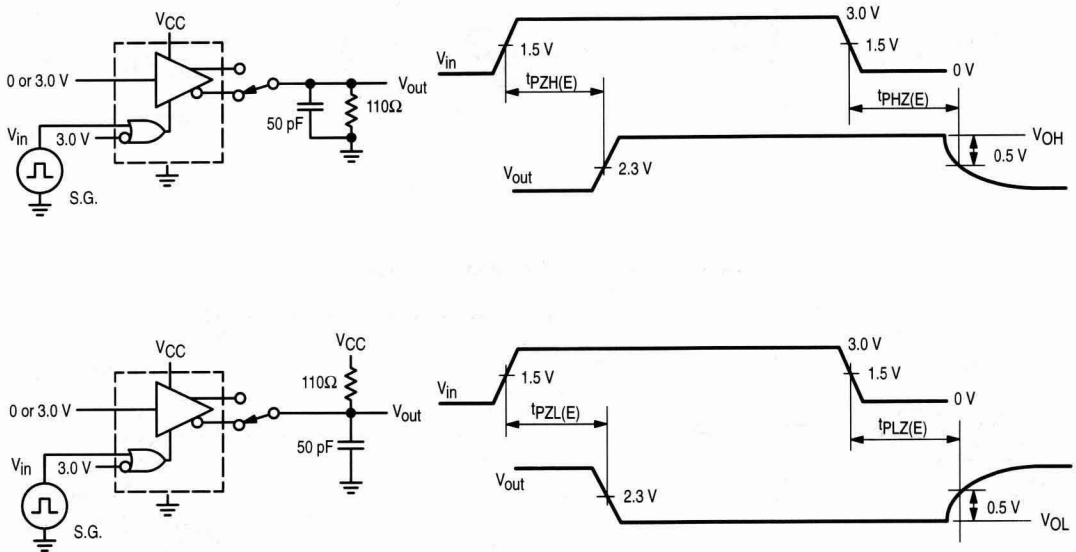
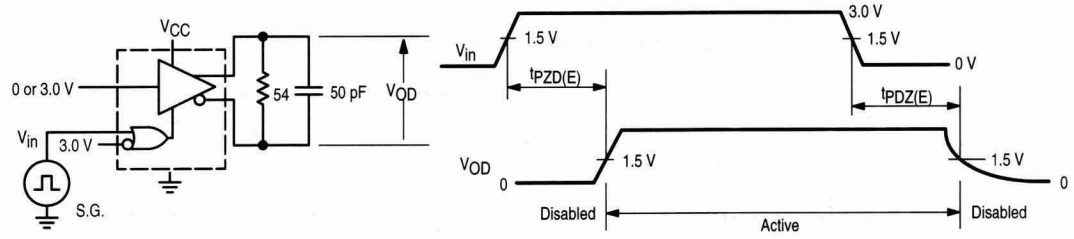



**Figure 6. Enable Timing, Differential Outputs**




**NOTES:** 1. S.G. set to: f ≤ 1.0 MHz; duty cycle = 50%; $t_r$, $t_f$, ≤ 5.0 ns.
2. $V_{in}$ is inverted for $\overline{\text{Enable}}$ measurements.

**Figure 7. Single–Ended Output Voltage versus Output Sink Current**

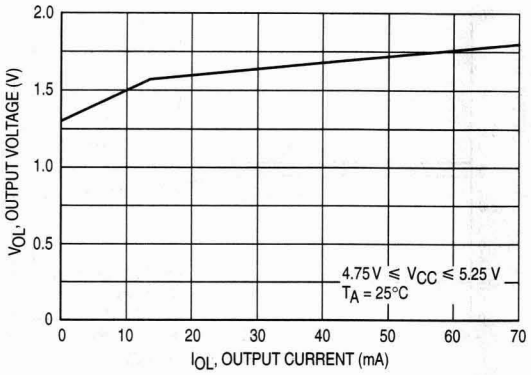



**Figure 8. Single–Ended Output Voltage versus Temperature**

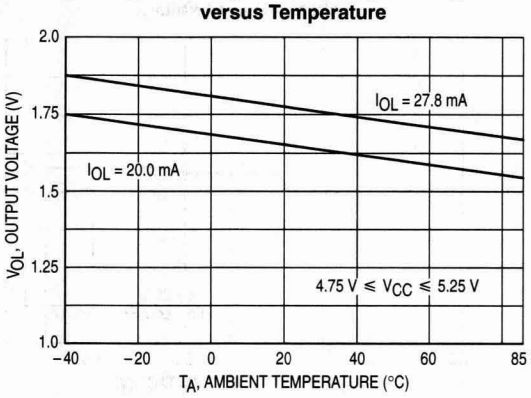



**Figure 9. Single–Ended Output Voltage versus Output Source Current**

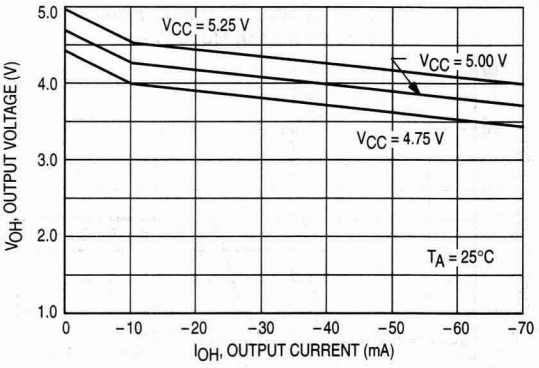



**Figure 10. Single–Ended Output Voltage versus Temperature**

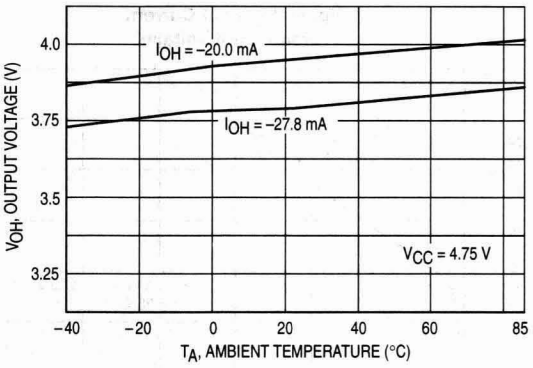



**Figure 11. Output Differential Voltage versus Load Current**

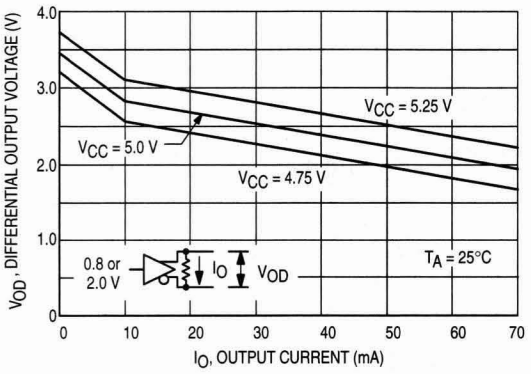



**Figure 12. Output Differential Voltage versus Temperature**

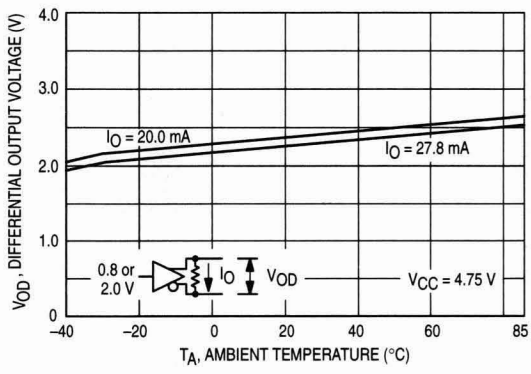



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**Figure 13. Output Leakage Current versus Output Voltage**

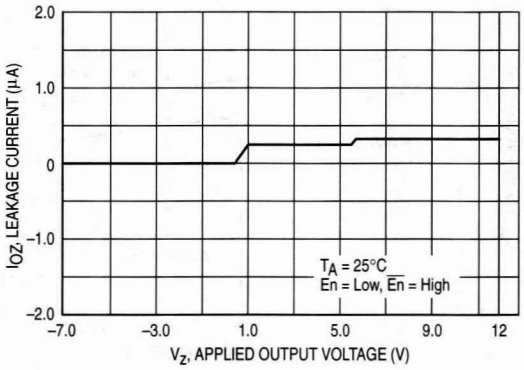


**Figure 14. Output Leakage Current versus Temperature**

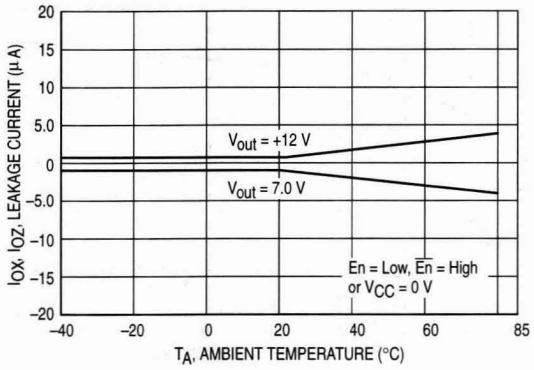


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**Figure 15. Input Current versus Input Voltage**

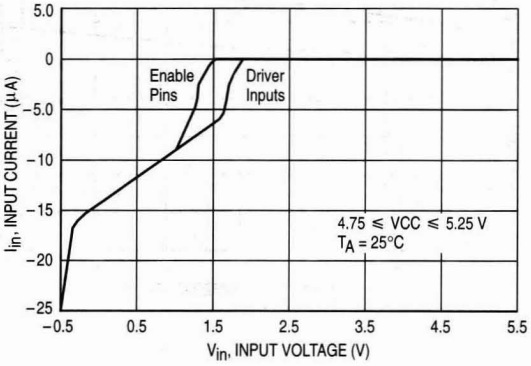
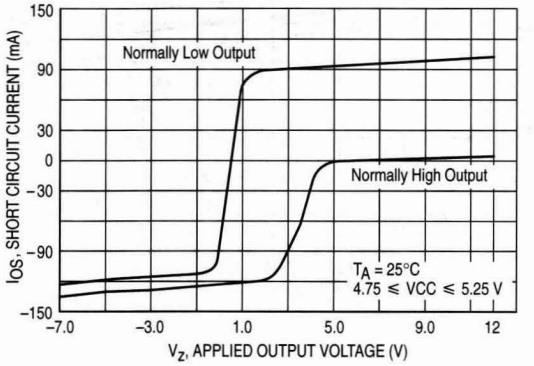



**Figure 16. Short Circuit Current versus Common Mode Voltage**



## APPLICATIONS INFORMATION

### Description

The MC75172B and MC75174B are differential line drivers designed to comply with EIA–485 Standard (April 1983) for use in balanced digital multipoint systems containing multiple drivers. The drivers also comply with EIA–422–A and CCITT Recommendations V.11 and X.27. The drivers meet the EIA–485 requirement for protection from damage in the event that two or more drivers attempt to transmit data simultaneoulsy on the same cable. Data rates in excess of 10 MBPS are possible, depending on the cable length and cable characteristics. A single power supply, 5.0 V, ±5%, is required at a nominal current of 60 mA, plus load currents.

### Outputs

Each output (when active) will be a low or a high voltage, which depends on the input state and the load current (see Table 1, 2 and Figures 7 to 10). The graphs apply to each driver, regardless of how many other drivers within the package are supplying load current.

**Table 1. MC75172B Truth Table**

| | Enables | | Outputs | |
|---|---|---|---|---|
| Data Input | EN | $\overline{EN}$ | Y | Z |
| H | H | X | H | L |
| L | H | X | L | H |
| H | X | L | H | L |
| L | X | L | L | H |
| X | L | H | Z | Z |

**Table 2. MC75174B Truth Table**

| | | Outputs | |
|---|---|---|---|
| Data Input | Enable | Y | Z |
| H | H | H | L |
| L | H | L | H |
| X | L | Z | Z |

H = Logic high, L = Logic low, X = Irrelevant, Z = High impedance

The two outputs of a driver are always complementary. A "high" output can only source current out, while a "low" output can only sink current (except for short circuit current – see Figure 16).

The outputs will be in the high impedance mode when:

a) the Enable inputs are set according to Table 1 or 2;

b) $V_{CC}$ is less than 1.5 V;

c) the junction temperature exceeds the trip point of the thermal shutdown circuit (see below). When in this condition, the output's source and sink capability are shut off, and only leakage currents will flow (see Figures 13, 14). Disabled outputs may be taken to any voltage between –7.0 V and 12 V without damage.

The drivers are protected from short circuits by two methods:

a) Current limiting is provided at each output, in both the source and sink direction, for shorts to any voltage within the range of 12 V to –7.0 V, with respect to circuit ground (see Figure 16). The short circuit current will flow until the fault is removed, or until the thermal shutdown circuit activates (see below). The current limiting circuit has a negative temperature coefficient and requires no resetting upon removal of the fault condition.

b) A thermal shutdown circuit disables the outputs when the junction temperature reaches 150°C, ±20°C. The thermal shutdown circuit has a hysteresis of ≈ 12°C to prevent oscillations. When this circuit activates, the output stage of each driver is put into the high impedance mode, thereby shutting off the output currents. The remainder of the internal circuitry remains biased. The outputs will become active once again as the IC cools down.

### Driver Inputs

The driver inputs determine the state of the outputs in accordance with Tables 1 and 2. The driver inputs have a nominal threshold of 1.2 V, and their voltage must be kept within the range of 0 V to $V_{CC}$ for proper operation. If the voltage is taken more than 0.5 V below ground, excessive currents will flow, and proper operation of the drivers will be affected. An open pin is equivalent to a logic high, but good design practices dictate that inputs should never be left open. The characteristics of the driver inputs are shown in Figure 15. This graph is not affected by the state of the Enable pins.

### Enable Logic

Each driver's outputs are active when the Enable inputs (Pins 4 and 12) are true according to Tables 1 and 2.

The Enable inputs have a nominal threshold of 1.2 V and their voltage must be kept within the range of 0 V to $V_{CC}$ for proper operation. If the voltage is taken more than 0.5 V below ground, excessive currents will flow, and proper operation of the drivers will be affected. An open pin is equivalent to a logic high, but good design practices dictate that inputs should never be left open. The Enable input characteristics are shown in Figure 15.

### Operating Temperature Range

The minimum ambient operating temperature is listed as –40°C to meet EIA–485 specifications, and 0°C to meet EIA–422–A specifications. The higher $V_{OD}$ required by EIA–422–A is the reason for the narrower temperature range.

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The maximum ambient operating temperature (applicable to both EIA–485 and EIA–422–A) is listed as 85°C. However, a lower ambient may be required depending on system use (i.e. specifically how many drivers within a package are used) and at what current levels they are operating. The maximum power which may be dissipated within the package is determined by:

$$PD_{max} = \frac{T_{Jmax} - T_A}{R_{\theta JA}}$$

where: $R_{\theta JA}$ = package thermal resistance (typical 70°C/W for the DIP package, 85°C/W for SOIC package);
$T_{Jmax}$ = max. operating junction temperature, and
$T_A$ = ambient temperature.

Since the thermal shutdown feature has a trip point of 150°C, ±20°C, $T_{Jmax}$ is selected to be 130°C. The power dissipated within the package is calculated from:

PD = $\{[(V_{CC} - V_{OH}) \bullet I_{OH}] + V_{OL} \bullet I_{OL})\}$ each driver + $(V_{CC} \bullet I_{CC})$

where: $V_{CC}$ = the supply voltage;
$V_{OH}$, $V_{OL}$ are measured or estimated from Figures 7 to 10;
$I_{CC}$ = the quiescent power supply current (typical 60 mA).

As indicated in the equation, the first term (in brackets) must be calculated and summed for each of the four drivers, while the last term is common to the entire package.

*Example 1:* $T_A$ = 25°C, $I_{OL} = I_{OH}$ = 55 mA for each driver, $V_{CC}$ = 5.0 V, DIP package. How many drivers per package can be used?

Maximum allowable power dissipation is:

$$PD_{max} = \frac{130°C - 25°C}{70°C/W} = 1.5\ W$$

Since the power supply current of 60 mA dissipates 300 mW, that leaves 1.2 W (1.5 W – 0.3 W) for the drivers. From Figures 7 and 9, $V_{OL} \approx 1.75$ V, and $V_{OH} \approx 3.85$ V. The power dissipated in each driver is:

$\{(5.0 - 3.85) \bullet 0.055\} + (1.75 \bullet 0.055) = 160$ mW.

Since each driver dissipates 160 mW, the four drivers per package could be used in this application

*Example 2:* $T_A$ = 85°C, $I_{OL}$ = 27.8 mA, $I_{OH}$ = 20 mA for each driver, $V_{CC}$ = 5.0 V, SOIC package. How many drivers per package can be used?

Maximum allowable power dissipation is:

$$PD_{max} = \frac{130°C - 85°C}{85°C/W} = 0.53\ W$$

Since the power supply current of 60 mA dissipates 300 mW, that leaves 230 mW (530 mW – 300 mW) for the drivers. From Figures 8 and 10 (adjusted for $V_{CC}$ = 5.0 V), $V_{OL} \approx 1.38$ V, and $V_{OH} \approx 4.27$ V. The power dissipated in each driver is:

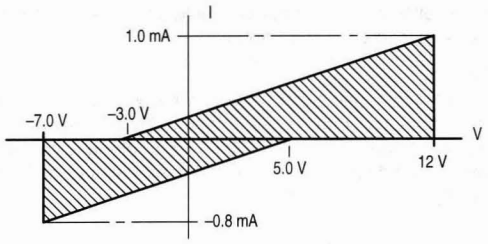
$\{(5.0 - 4.27) \bullet 0.020\} + (1.38 \bullet 0.0278) = 53$ mW

Since each driver dissipates 53 mW, the use of all four drivers in a package would be marginal. Options include reducing the load current, reducing the ambient temperature, and/or providing a heat sink.

### System Requirements

EIA–485 requires each driver to be capable of transmitting data differentially to at least 32 unit loads, plus an equivalent DC termination resistance of 60Ω, over a common mode voltage of –7.0 to 12 V. A unit load (U.L.), as defined by EIA–485, is shown in Figure 17.

**Figure 17. Unit Load Definition**




Reprinted from EIA–485, Electronic Industries Association, Washington,DC.

A load current within the shaded regions represents an impedance of less than one U.L., while a load current of a magnitude outside the shaded area is greater than one U.L. A system's total load is the sum of the unit load equivalents of each receiver's input current, and each disabled driver's output leakage current. The 60Ω termination resistance mentioned above allows for two 120Ω terminating resistors.

Using the EIA–485 requirements (worst case limits), and the graphs of Figures 7 and 9, it can be determined that the maximum current an MC75172B or MC75174B driver will source or sink is ≈65 mA.

### System Example

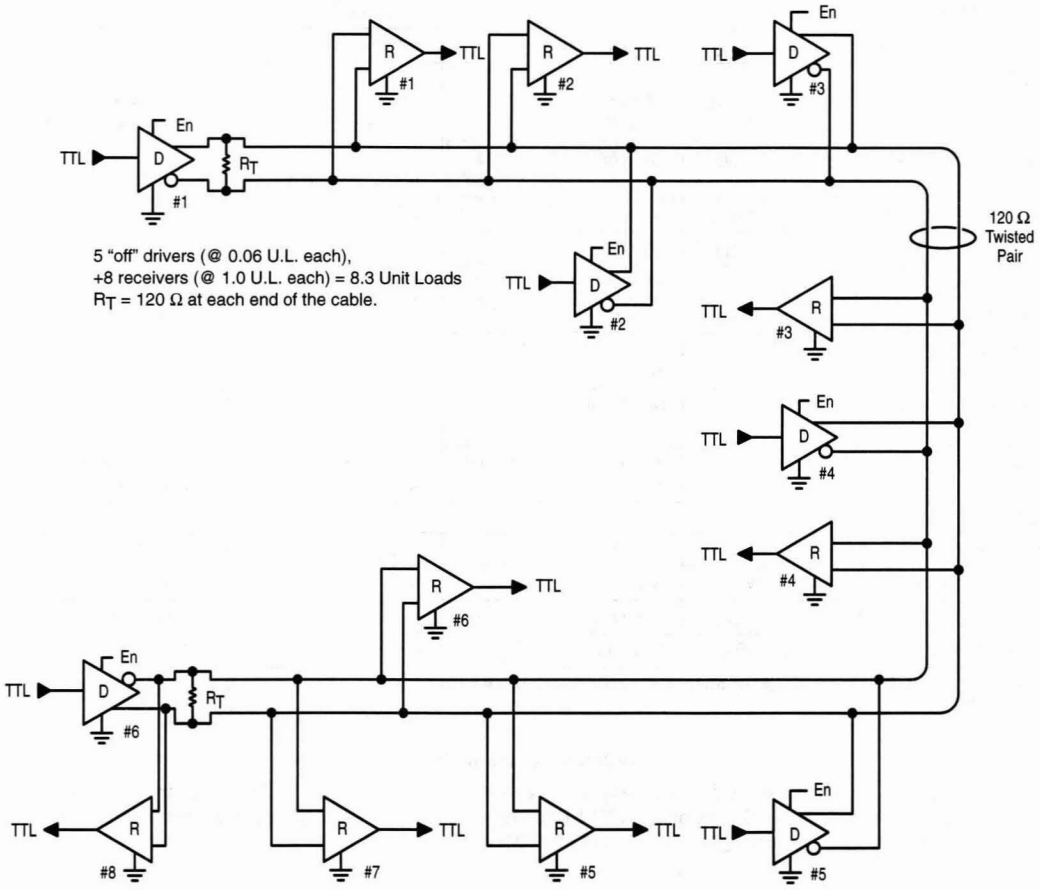
An example of a typical EIA–485 system is shown in Figure 18. In this example, it is assumed each receiver's input characteristics correspond to 1.0 U.L. as defined in Figure 17. Each "off" driver, with a maximum leakage of ±50 μA over the common mode range, presents a load of ≈0.06 U.L. The total load for the active driver is therefore 8.3 unit loads, plus the parallel combination of the two terminating resistors (60Ω). It is up to the system software to control the driver Enable pins to ensure that only one driver is active at any time.

### Termination Resistors

Transmission line theory states that, in order to preserve the shape and integrity of a waveform traveling along a cable, the cable must be terminated in an impedance equal to its characteristic impedance. In a system such as that depicted in Figure 18, in which data can travel in both directions, both physical ends of the cable must be terminated. Stubs, leading to each receiver and driver, should be as short as possible.

Leaving off the terminations will generally result in reflections which can have amplitudes of several volts above $V_{CC}$ or below ground. These overshoots and undershoots can disrupt the driver and/or receiver operation, create false data, and in some cases damage components on the bus.

**Figure 18. Typical EIA–485 System**




**NOTES:** 1. Terminating resistors $R_T$ must be located at the physical ends of the cable.
2. Stubs should be as short as possible.
3. Circuit ground of all drivers and receivers must be connected via a dedicated wire within the cable. Do not rely on chassis ground or power line ground.

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### Comparing System Requirements

| Characteristic | Symbol | EIA–485 | EIA–422–A | V.11 and X.27 |
|---|---|---|---|---|
| **GENERATOR (DRIVER)** | | | | |
| Output Impedance (Note 1) | $Z_{out}$ | Not Specified | < 100 Ω | 50 10 100 Ω |
| Open Circuit Voltage<br>Differential<br>Single–Ended | <br>$V_{OCD}$<br>$V_{OCS}$ | <br>1.5 to 6.0 V<br>< 6.0 V | <br>≤ 6.0 V<br>≤ 6.0 V | <br>≤ 6.0 V, w/3.9 kΩ, Load<br>≤ 6.0 V, w/3.9 kΩ, Load |
| Loaded Differential Voltage | $V_{OD}$ | 1.5 to 5.0 V, w/54 Ω load | ≥ 2.0 V or ≥ 0.5 $V_{OCD}$, w/100 Ω load | ≥ 2.0 V or ≥ 0.5 $V_{OCD}$, w/100 Ω load |
| Differential Voltage Balance | $\Delta V_{OD}$ | < 200 mV | ≤ 400 mV | < 400 mV |
| Output Common Mode Range | $V_{CM}$ | –7.0 to +12 V | Not Specified | Not Specified |
| Offset Voltage | $V_{OS}$ | –1.0 < $V_{OS}$ < 3.0 V | ≤ 3.0 V | ≤ 3.0 V |
| Offset Voltage Balance | $\Delta V_{OS}$ | < 200 mV | ≤ 400 mV | < 400 mV |
| Short Circuit Current | $I_{OS}$ | ≤ 250 mA for –7.0 to 12 V | ≤ 150 mA to ground | ≤ 150 mA to ground |
| Leakage Current ($V_{CC}$ = 0) | $I_{OLK}$ | Not Specified | ≤ 100 µA to –0.25 V thru 6.0 V | ≤ 100 µA to ± 0.25 V |
| Output Rise/Fall Time (Note 2) | $t_r$, $t_f$ | ≤ 0.3 $T_B$, w/54 Ω/1150 pF load | ≤ 0.1 $T_B$ or ≤ 20 ns, w/100 Ω load | ≤ 0.1 $T_B$ or ≤ 20 ns, w/100 Ω load |
| **RECEIVER** | | | | |
| Input Sensitivity | $V_{th}$ | ± 200 mV | ± 200 mV | ± 300 mV |
| Input Bias Voltage | $V_{bias}$ | ≤ 3.0 V | ≤ 3.0 V | ≤ 3.0 V |
| Input Common Mode Range | $V_{cm}$ | –7.0 to 12 V | –7.0 to 7.0 V | –7.0 to 7.0 V |
| Dynamic Input Impedance | $R_{in}$ | Spec number of U.L. | ≥ 4 kΩ | ≥ 4 kΩ |

**NOTES:** 1. Compliance with V.11 and X.27 (Blue book) output impedance requires external resistors in series with the outputs of the MC75172B and MC75174B.
2. $T_B$ = Bit time.

### Additional Information

Copies of the EIA Recommendations (EIA–485 and EIA–422–A) can be obtained from the Electronics Industries Association, Washington, D.C. (202–457–4966). Copies of the CCITT Recommendations (V.11 and X.27) can be obtained from the United States Department of Commerce, Springfield, VA (703–487–4600).

MOTOROLA

# SN75175

## Quad EIA-485 Line Receiver

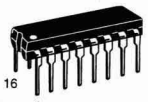
**QUAD EIA–485 LINE RECEIVER WITH THREE–STATE OUTPUTS**

**SEMICONDUCTOR TECHNICAL DATA**

The Motorola SN75175 is a monolithic quad differential line receiver with three–state outputs. It is designed specifically to meet the requirements of EIA–485, EIA–422A/23A Standards and CCITT recommendations.

The device is optimized for balanced multipoint bus transmission at rates up to 10 megabits per second. It also features high input impedance, input hysteresis for increased noise immunity, and input sensitivity of ±200 mV over a common mode input voltage range of –12 V to 12 V. The SN75175 is designed for optimum performance when used with the SN75172 or SN75174 quad differential line drivers.

- Meets EIA Standards EIA–422A and EIA–423A, EIA–485
- Meets CCITT Recommendations V.10, V.11, X.26, and X.27
- Designed for Multipoint Transmission on Long Bus Lines in Noisy Environments
- 3–State Outputs
- Common–Mode Input Voltage Range . . . –12 V to 12 V
- Input Sensitivity . . . ±200 mV
- Input Hysteresis . . . 50 mV Typ
- High Input Impedance . . . 1 EIA–485 Unit Load
- Operates from Single 5.0 V Supply
- Lower Power Requirements
- Plug–In Replacement for MC3486



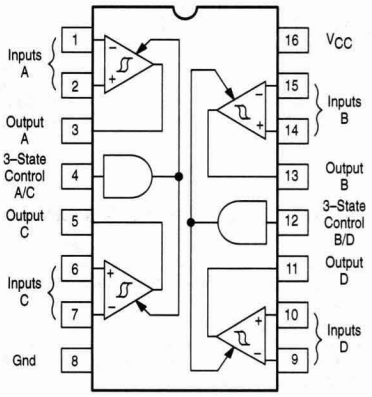

**N SUFFIX**
PLASTIC PACKAGE
CASE 648

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

7

This device contains 174 active transistors.

**PIN CONNECTIONS**




(Top View)

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 | Vdc |
| Input Common Mode Voltage | $V_{ICM}$ | ±25 | Vdc |
| Input Differential Voltage | $V_{ID}$ | ±25 | Vdc |
| Three–State Control Input Voltage | $V_I$ | 7.0 | Vdc |
| Output Sink Current | $I_O$ | 50 | mA |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Operating Junction Temperature | $T_J$ | +150 | °C |

**NOTE:** ESD data available upon request.

**RECOMMENDED OPERATING CONDITIONS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 4.75 to 5.25 | Vdc |
| Operating Ambient Temperature | $T_A$ | 0 to +70 | °C |
| Input Common Mode Voltage Range | $V_{ICM}$ | –12 to +12 | Vdc |
| Input Differential Voltage Range | $V_{IDR}$ | –12 to +12 | Vdc |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| SN75175N | $T_A$ = 0 to +70°C | Plastic DIP |
| SN75175D | | SO–16 |

**ELECTRICAL CHARACTERISTICS** (Unless otherwise noted, minimum and maximum limits apply over recommended temperature and power supply voltage ranges. Typical values are for $T_A$ = 25°C, $V_{CC}$ = 5.0 V, and $V_{ICM}$ = 0 V, Note 1.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Differential Input Threshold Voltage (Note 2)<br>(–12 V ≤ $V_{ICM}$ ≤ 12 V, $V_{IH}$ = 2.0 V)<br>($I_O$ = –0.4 mA, $V_{OH}$ ≥ 2.7 V)<br>($I_O$ = 16 mA, $V_{OL}$ ≤ 0.5 V) | $V_{TH(D)}$ | <br><br>–<br>– | <br><br>–<br>– | <br><br>0.2<br>–0.2 | V |
| Input Hysteresis | $V_{T+} - V_{T-}$ | – | 50 | – | mV |
| Input Line Current (Differential Inputs)<br>(Unmeasured Input at 0 V, Note 3)<br>($V_I$ = 12 V)<br>($V_I$ = –7.0 V) | $I_I$ | <br><br>–<br>– | <br><br>–<br>– | <br><br>1.0<br>–0.8 | mA |
| Input Resistance (Note 4) | $r_i$ | 1 Unit Load | – | – | |
| Input Balance and Output Level (Note 3)<br>(–12 V ≤ $V_{ICM}$ ≤ 12 V, $V_{IH}$ = 2.0 V)<br>($I_O$ = –0.4 mA, $V_{ID}$ = 0.2 V)<br>($I_O$ = 8.0 mA, $V_{ID}$ = –0.2 V)<br>($I_O$ = 16 mA, $V_{ID}$ = –0.2 V) | <br><br>$V_{OH}$<br>$V_{OL}$<br>$V_{OL}$ | <br><br>2.7<br>–<br>– | <br><br>–<br>–<br>– | <br><br>–<br>0.45<br>0.5 | V |
| Input Voltage – High Logic State (Three–State Control) | $V_{IH}$ | 2.0 | – | – | V |
| Input Voltage – Low Logic State (Three–State Control) | $V_{IL}$ | – | – | 0.8 | V |
| Input Current – High Logic State (Three–State Control)<br>($V_{IH}$ = 2.7 V)<br>($V_{IH}$ = 5.5 V) | $I_{IH}$ | <br>–<br>– | <br>–<br>– | <br>20<br>100 | μA |
| Input Current – Low Logic State (Three–State Control)<br>($V_{IL}$ = 0.4 V) | $I_{IL}$ | – | – | –100 | μA |
| Input Clamp Diode Voltage (Three–State Control)<br>($I_{IK}$ = –18 mA) | $V_{IK}$ | – | – | –1.5 | V |
| Output Third State Leakage Current<br>($V_{I(D)}$ = 3.0 V, $V_{IL}$ = 0.8 V, $V_O$ = 0.4 V)<br>($V_{I(D)}$ = –3.0 V, $V_{IL}$ = 0.8 V, $V_O$ = 2.4 V) | $I_{OZ}$ | <br>–<br>– | <br>–<br>– | <br>–20<br>20 | μA |
| Output Short–Circuit Current (Note 5)<br>($V_{I(D)}$ = 3.0 V, $V_{IH}$ = 2.0 V, $V_O$ = 0 V) | $I_{OS}$ | –15 | – | –85 | mA |
| Power Supply Current ($V_{IL}$ = 0 V) (All Inputs Grounded) | $I_{CC}$ | – | – | 70 | mA |

**NOTES:** 1. All currents into device pins are shown as positive, out of device pins are negative. All voltages referenced to ground unless otherwise noted.
2. Differential input threshold voltage and guaranteed output levels are done simultaneously for worst case.
3. Refer to EIA–485 for exact conditions. Input balance and guaranteed output levels are done simultaneously for worst case.
4. Input resistance should be derived from input line current specifications and is shown for reference only. See EIA–485 and input line current specifications for more specific input resistance information.
5. Only one output at a time should be shorted.

**SWITCHING CHARACTERISTICS** (Unless otherwise noted, $V_{CC}$ = 5.0 V and $T_A$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Propagation Delay Time – Differential Inputs to Output<br>Output High to Low<br>Output Low to High | <br>$t_{PHL(D)}$<br>$t_{PLH(D)}$ | <br>–<br>– | <br>25<br>25 | <br>35<br>35 | ns |
| Propagation Delay Time – Three–State Control to Output<br>Output Low to Third State<br>Output High to Third State<br>Output Third State to High<br>Output Third State to Low | <br>$t_{PLZ}$<br>$t_{PHZ}$<br>$t_{PZH}$<br>$t_{PZL}$ | <br>–<br>–<br>–<br>– | <br>16<br>19<br>11<br>11 | <br>35<br>35<br>30<br>30 | ns |

**FUNCTION TABLE (EACH RECEIVER)**

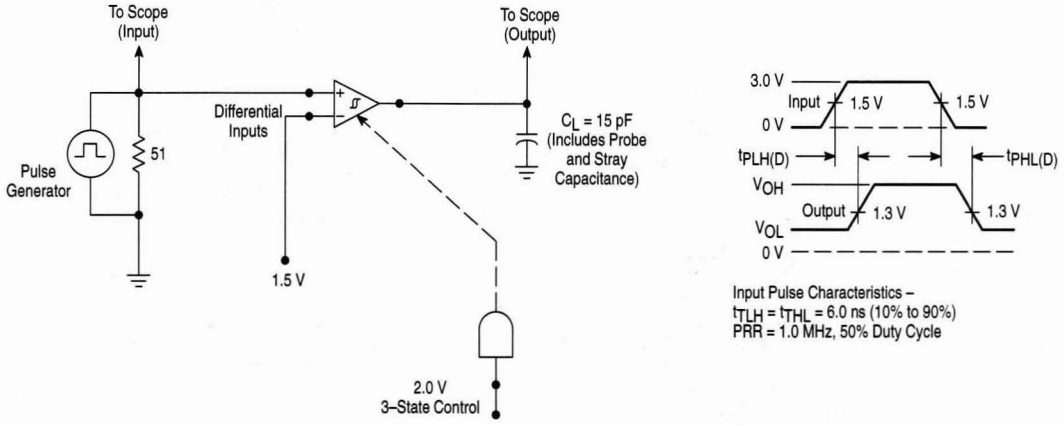
| Differential Inputs | 3–State Control | Output Y |
|---|---|---|
| $V_{ID} \geq 2.0$ V | H | H |
| $-0.2$ V $< V_{ID} < 0.2$ V | H | ? |
| $V_{ID} \leq -0.2$ V | H | L |
| X | L | Z |

H = high level
L = low level
X = irrelevant

? = indeterminate
Z = high–impedance (off)

**SWITCHING TEST CIRCUIT AND WAVEFORMS**

**Figure 1. Propagation Delay, Differential Input to Output**




Input Pulse Characteristics –
$t_{TLH} = t_{THL}$ = 6.0 ns (10% to 90%)
PRR = 1.0 MHz, 50% Duty Cycle

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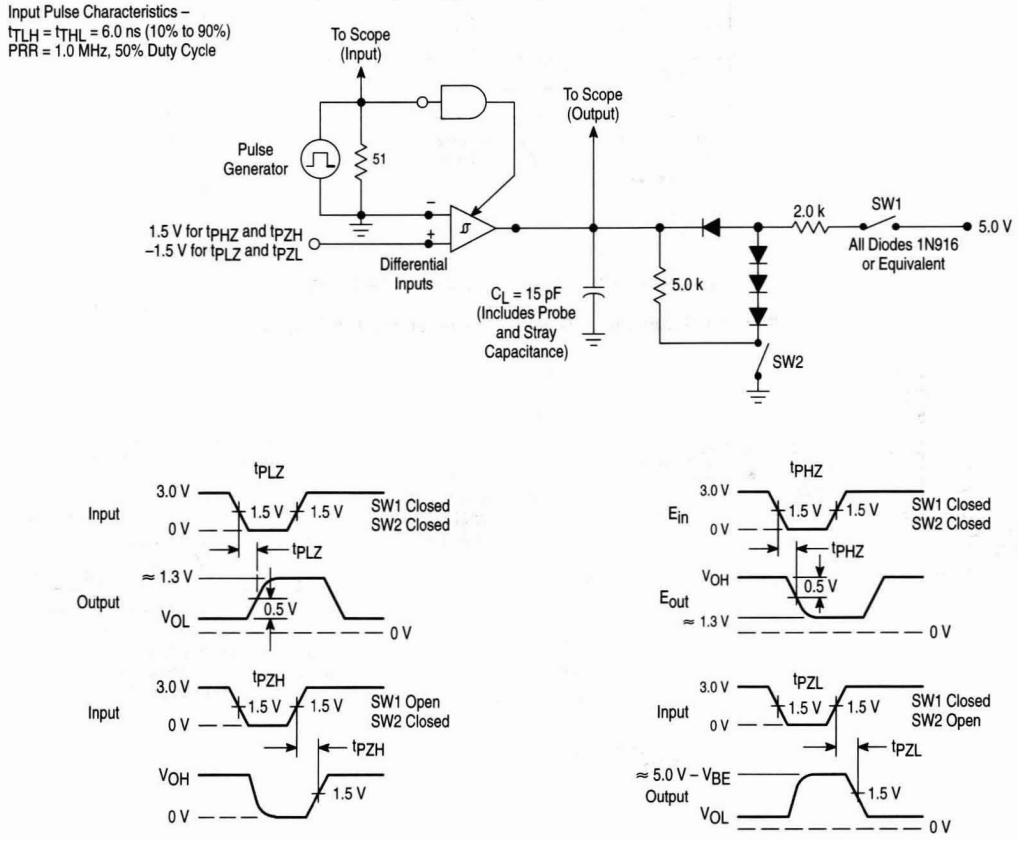
**SWITCHING TEST CIRCUIT AND WAVEFORMS** (continued)

**Figure 2. Propagation Delay, Three–State Control Input to Output**



## TYPICAL CHARACTERISTICS

**Figure 3. Output Voltage versus Differential Input Voltage**

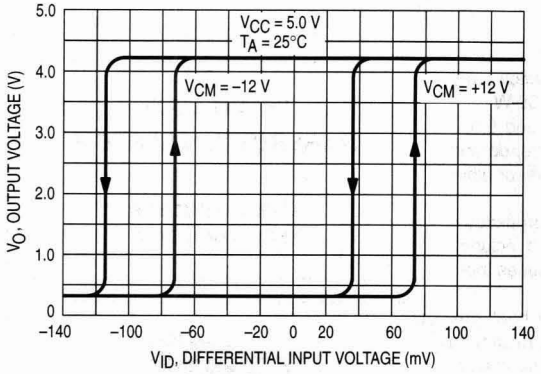



**Figure 4. Output Voltage versus 3–State Control Voltage**

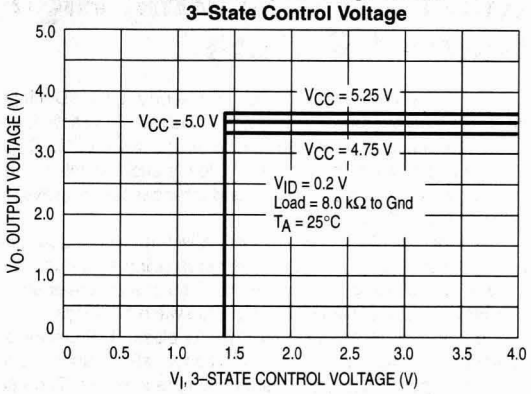



**Figure 5. High Level Output Voltage versus Output Current**

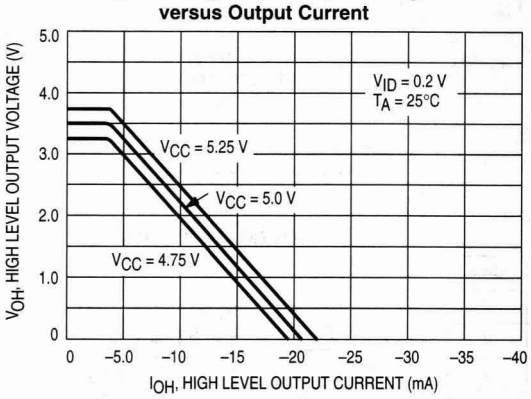



**Figure 6. Low Level Output Voltage versus Output Current**

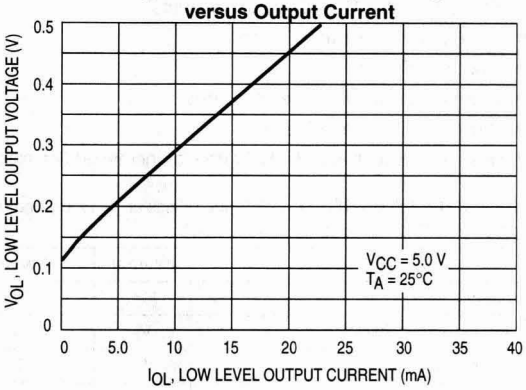



**Figure 7. High Level Output Voltage versus Temperature**

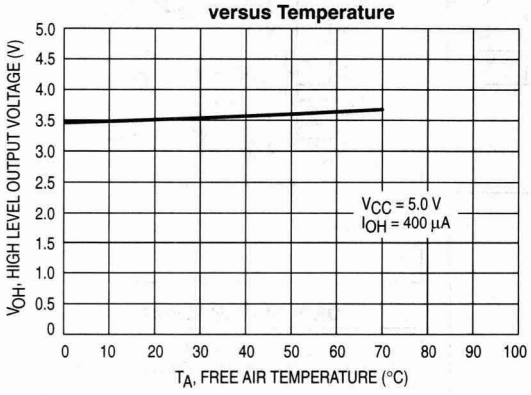
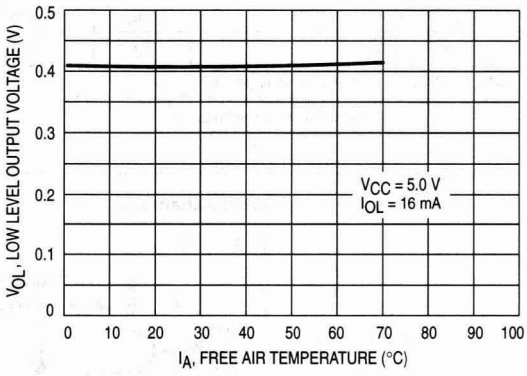



**Figure 8. Low Level Output Voltage versus Temperature**

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MOTOROLA

# Quad 1.5 A Sinking High Current Switch

**ULN2068**

**QUAD 1.5 A DARLINGTON SWITCH**

**SEMICONDUCTOR TECHNICAL DATA**

Not Recommended For New Designs

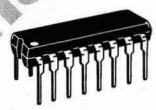
The ULN2068 is a high–voltage, high–current quad Darlington switch array designed for high current loads, both resistive and reactive, up to 300 W.

It is intended for interfacing between low level (TTL, DTL, LS and 5.0 V CMOS) logic families and peripheral loads such as relays, solenoids, dc and stepping motors, multiplexer LED and incandescent displays, heaters, or other high voltage, high current loads.

The Motorola ULN2068 is specified with minimum guaranteed breakdown of 50 V and is 100% tested for safe area using an inductive load. It includes integral transient suppression diodes. Use of a predriver stage reduces input current while still allowing the device to switch 1.5 Amps.

It is supplied in an improved 16–Pin plastic DIP package with heat sink contact tabs (Pins 4, 5, 12 and 13). A copper alloy lead frame allows maximum power dissipation using standard cooling techniques. The use of the contact tab lead frame facilitates attachment of a DIP heat sink while permitting the use of standard layout and mounting practices.

- TTL, DTL, LS, CMOS Compatible Inputs
- 1.5 A Maximum Output Current
- Low Input Current
- Internal Freewheeling Clamp Diodes
- 100% Inductive Load Tested
- Heat Tab Copper Alloy Lead Frame for Increased Dissipation



**B SUFFIX**
PLASTIC PACKAGE
CASE 648C

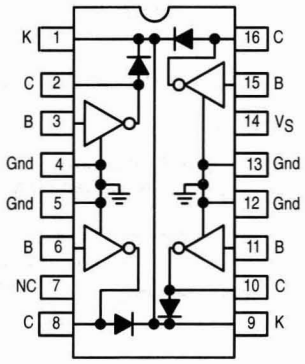
7

**MAXIMUM RATINGS** ($T_A$ = 25°C and ratings apply to any one device in the package, unless otherwise noted)

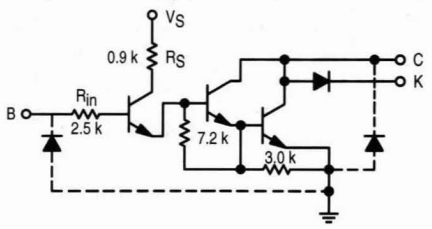
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Output Voltage | $V_O$ | 50 | V |
| Input Voltage (Note 1) | $V_I$ | 15 | V |
| Supply Voltage | $V_S$ | 10 | V |
| Collector Current (Note 2) | $I_C$ | 1.75 | A |
| Input Current (Note 3) | $I_I$ | 25 | mA |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +150 | °C |
| Junction Temperature | $T_J$ | 150 | °C |

**NOTES:** 1. Input voltage referenced to ground.
2. Allowable output conditions shown in Figures 11 and 12.
3. May be limited by max input voltage.

**PIN CONNECTIONS**




**Partial Schematic**




**ORDERING INFORMATION***

| Device | Operating Temperature Range | Package |
|---|---|---|
| ULN2068B | $T_A$ = 0 to +70°C | Plastic DIP |

*Other options of this ULN2060/2070 series are available for volume applications. Contact your local Motorola Sales Representative.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Output Leakage Current (Figure 1)<br>($V_{CE}$ = 50 V)<br>($V_{CE}$ = 50 V, $T_A$ = 70°C) | $I_{CEX}$ | <br>–<br>– | <br>–<br>– | <br>100<br>500 | µA |
| Collector–Emitter Saturation Voltage (Figure 2)<br>($I_C$ = 500 mA<br>($I_C$ = 750 mA<br>($I_C$ = 1.0 A<br>($I_C$ = 1.25 A } $V_{in}$ = 2.4 V) | $V_{CE(sat)}$ | <br>–<br>–<br>–<br>– | <br>–<br>–<br>–<br>– | <br>1.13<br>1.25<br>1.40<br>1.60 | V |
| Input Current – On Condition (Figure 4)<br>($V_I$ = 2.4 V)<br>($V_I$ = 3.75 V) | $I_{I(on)}$ | <br>–<br>– | <br>–<br>– | <br>0.25<br>1.0 | mA |
| Input Voltage – On Condition (Figure 5)<br>($V_{CE}$ = 2.0 V, $I_C$ = 1.5 A) | $V_{I(on)}$ | <br>– | <br>– | <br>2.4 | V |
| Inductive Load Test (Figure 3)<br>($V_S$ = 5.5 V, $V_{CC}$ = 24.5 V,<br>$t_{PW}$ = 4.0 ms) | $\Delta V_{out}$ | <br>– | <br>– | <br>100 | mV |
| Supply Current (Figure 8)<br>($I_C$ = 500 mA, $V_{in}$ = 2.4 V, $V_S$ = 5.5 V) | $I_S$ | <br>– | <br>– | <br>6.0 | mA |
| Turn–On Delay Time<br>(50% $E_I$ to 50% $E_O$) | $t_{PHL}$ | <br>– | <br>– | <br>1.0 | µs |
| Turn–Off Delay Time<br>(50% $E_I$ to 50% $E_O$) | $t_{PLH}$ | <br>– | <br>– | <br>4.0 | µs |
| Clamp Diode Leakage Current (Figure 6)<br>($V_R$ = 50 V)<br>($V_R$ = 50 V, $T_A$ = 70°C) | $I_R$ | <br>–<br>– | <br>–<br>– | <br>50<br>100 | µA |
| Clamp Diode Forward Voltage (Figure 7)<br>($I_F$ = 1.0 A)<br>($I_F$ = 1.5 A) | $V_F$ | <br>–<br>– | <br>–<br>– | <br>1.75<br>2.0 | V |

Not Recommended For New Designs

## TEST FIGURES

**Figure 1.**

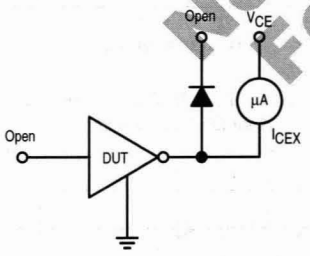



**Figure 2.**

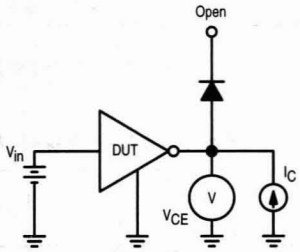



**Figure 3.**

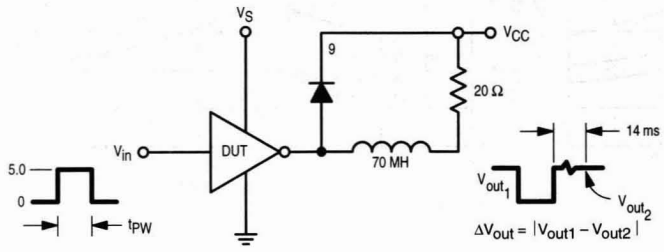
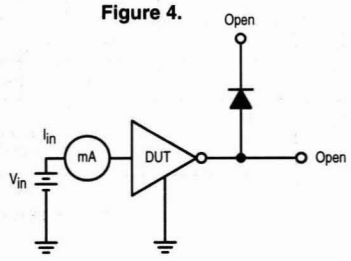



**Figure 4.**

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**TEST FIGURES** (continued)

**Figure 5.**

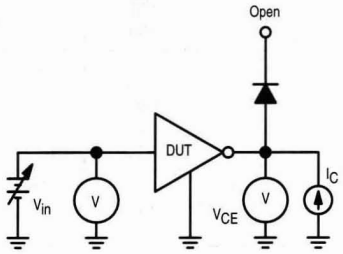



**Figure 6.**

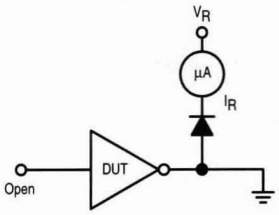



**Figure 7.**

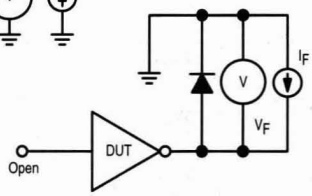
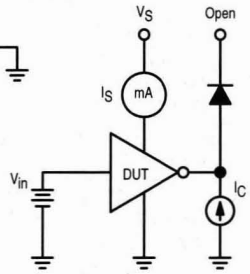



**Figure 8.**




**TYPICAL CHARACTERISTIC CURVES – $T_A$ = 25°C**

**Figure 9. Input Current versus Input Voltage**

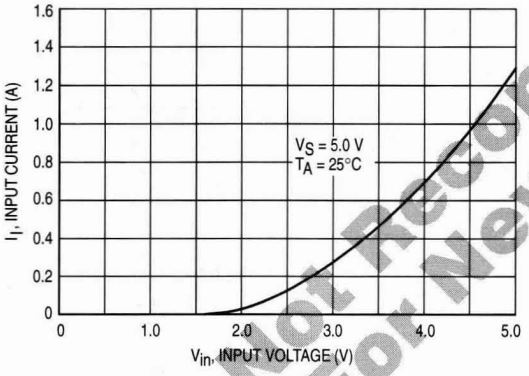



**Figure 10. Collector Current versus Input Current**

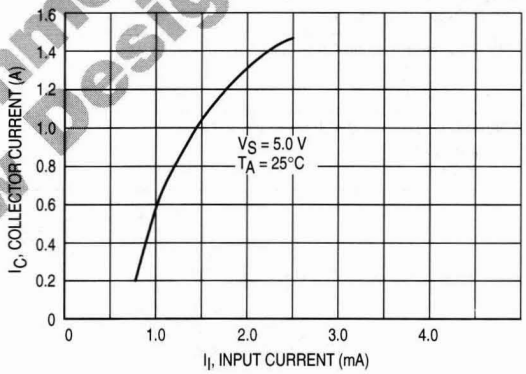



**Figure 11. $T_A$ = 70°C w/o Heat Sink**

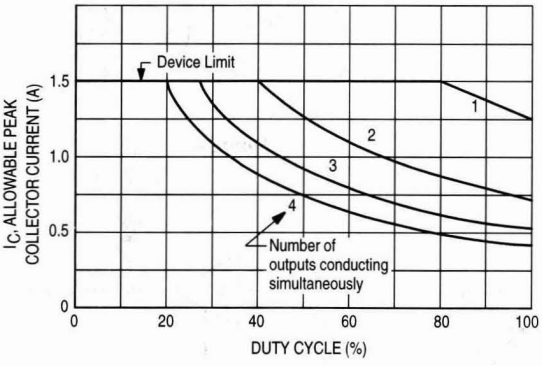



**Figure 12. $T_A$ = 70°C w/Staver V–8 Heat Sink (37.5°C/W)**

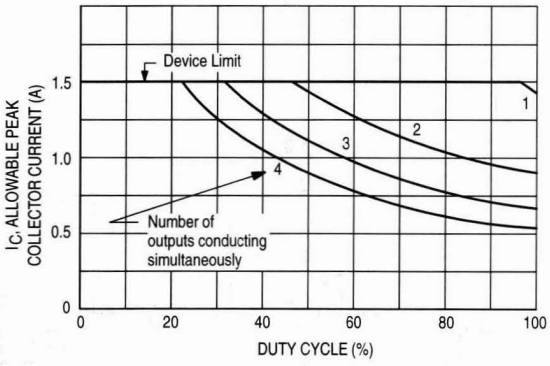



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**Figure 13. $T_A$ = 70°C w/Staver V–7 Heat Sink (27.5°C/W)**

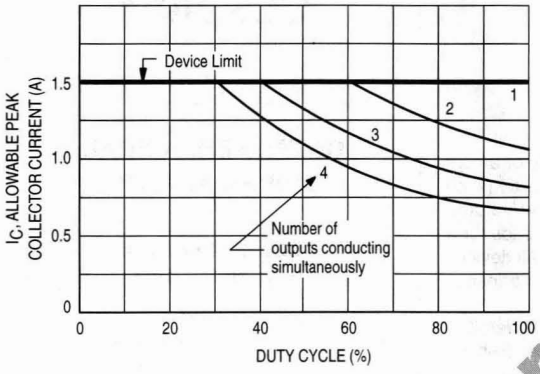



**Figure 14. $T_A$ = 50°C w/o Heat Sink**

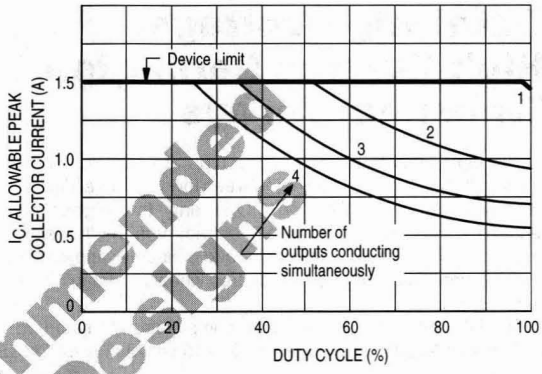



**Figure 15. $T_A$ = 50°C w/Staver V–8 Heat Sink (37.5°C/W)**

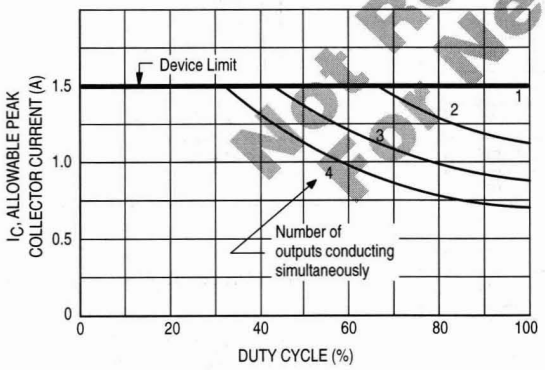
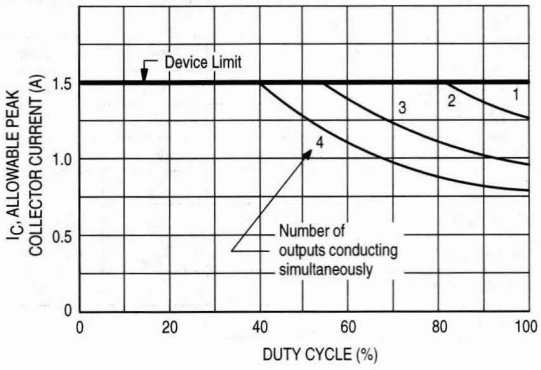



**Figure 16. $T_A$ = 50°C w/Staver V–7 Heat Sink (27.5°C/W)**




Not Recommended For New Designs

7

MOTOROLA

# Octal High Voltage, High Current Darlington Transistor Arrays

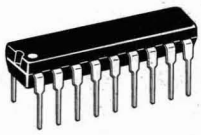
**ULN2803**
**ULN2804**

**OCTAL PERIPHERAL DRIVER ARRAYS**

**SEMICONDUCTOR TECHNICAL DATA**

The eight NPN Darlington connected transistors in this family of arrays are ideally suited for interfacing between low logic level digital circuitry (such as TTL, CMOS or PMOS/NMOS) and the higher current/voltage requirements of lamps, relays, printer hammers or other similar loads for a broad range of computer, industrial, and consumer applications. All devices feature open–collector outputs and free wheeling clamp diodes for transient suppression.

The ULN2803 is designed to be compatible with standard TTL families while the ULN2804 is optimized for 6 to 15 volt high level CMOS or PMOS.



**A SUFFIX**
PLASTIC PACKAGE
CASE 707

**MAXIMUM RATINGS** ($T_A$ = 25°C and rating apply to any one device in the package, unless otherwise noted.)

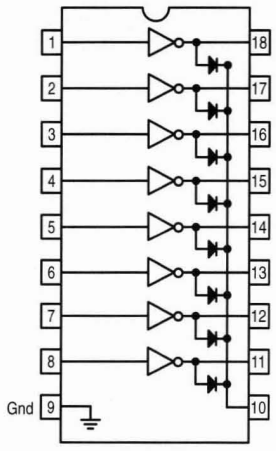
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Output Voltage | $V_O$ | 50 | V |
| Input Voltage (Except ULN2801) | $V_I$ | 30 | V |
| Collector Current – Continuous | $I_C$ | 500 | mA |
| Base Current – Continuous | $I_B$ | 25 | mA |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | −55 to +150 | °C |
| Junction Temperature | $T_J$ | 125 | °C |

$R_{\theta JA}$ = 55°C/W
Do not exceed maximum current limit per driver.

**ORDERING INFORMATION**

| Device | Characteristics | | |
|---|---|---|---|
| | Input Compatibility | $V_{CE(Max)}/I_{C(Max)}$ | Operating Temperature Range |
| ULN2803A<br>ULN2804A | TTL, 5.0 V CMOS<br>6 to 15 V CMOS, PMOS | 50 V/500 mA | $T_A$ = 0 to + 70°C |

**PIN CONNECTIONS**



**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Output Leakage Current (Figure 1) | | $I_{CEX}$ | | | | μA |
| ($V_O$ = 50 V, $T_A$ = +70°C) | All Types | | – | – | 100 | |
| ($V_O$ = 50 V, $T_A$ = +25°C) | All Types | | – | – | 50 | |
| ($V_O$ = 50 V, $T_A$ = +70°C, $V_I$ = 6.0 V) | ULN2802 | | – | – | 500 | |
| ($V_O$ = 50 V, $T_A$ = +70°C, $V_I$ = 1.0 V) | ULN2804 | | – | – | 500 | |
| Collector–Emitter Saturation Voltage (Figure 2) | | $V_{CE(sat)}$ | | | | V |
| ($I_C$ = 350 mA, $I_B$ = 500 μA) | All Types | | – | 1.1 | 1.6 | |
| ($I_C$ = 200 mA, $I_B$ = 350 μA) | All Types | | – | 0.95 | 1.3 | |
| ($I_C$ = 100 mA, $I_B$ = 250 μA) | All Types | | – | 0.85 | 1.1 | |
| Input Current – On Condition (Figure 4) | | $I_{I(on)}$ | | | | mA |
| ($V_I$ = 17 V) | ULN2802 | | – | 0.82 | 1.25 | |
| ($V_I$ = 3.85 V) | ULN2803 | | – | 0.93 | 1.35 | |
| ($V_I$ = 5.0 V) | ULN2804 | | – | 0.35 | 0.5 | |
| ($V_I$ = 12 V) | ULN2804 | | – | 1.0 | 1.45 | |
| Input Voltage – On Condition (Figure 5) | | $V_{I(on)}$ | | | | V |
| ($V_{CE}$ = 2.0 V, $I_C$ = 300 mA) | ULN2802 | | – | – | 13 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 200 mA) | ULN2803 | | – | – | 2.4 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 250 mA) | ULN2803 | | – | – | 2.7 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 300 mA) | ULN2803 | | – | – | 3.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 125 mA) | ULN2804 | | – | – | 5.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 200 mA) | ULN2804 | | – | – | 6.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 275 mA) | ULN2804 | | – | – | 7.0 | |
| ($V_{CE}$ = 2.0 V, $I_C$ = 350 mA) | ULN2804 | | – | – | 8.0 | |
| Input Current – Off Condition (Figure 3)<br>($I_C$ = 500 μA, $T_A$ = +70°C) | All Types | $I_{I(off)}$ | 50 | 100 | – | μA |
| DC Current Gain (Figure 2)<br>($V_{CE}$ = 2.0 V, $I_C$ = 350 mA) | ULN2801 | $h_{FE}$ | 1000 | – | – | – |
| Input Capacitance | | $C_I$ | – | 15 | 25 | pF |
| Turn–On Delay Time<br>(50% $E_I$ to 50% $E_O$) | | $t_{on}$ | – | 0.25 | 1.0 | μs |
| Turn–Off Delay Time<br>(50% $E_I$ to 50% $E_O$) | | $t_{off}$ | – | 0.25 | 1.0 | μs |
| Clamp Diode Leakage Current (Figure 6)<br>($V_R$ = 50 V) | $T_A$ = +25°C<br>$T_A$ = +70°C | $I_R$ | – | – | 50<br>100 | μA |
| Clamp Diode Forward Voltage (Figure 7)<br>($I_F$ = 350 mA) | | $V_F$ | – | 1.5 | 2.0 | V |

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## TEST FIGURES

(See Figure Numbers in Electrical Characteristics Table)

**Figure 1.**

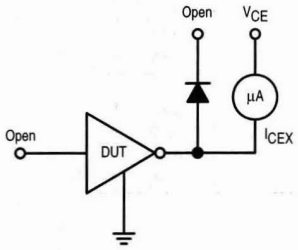



**Figure 2.**

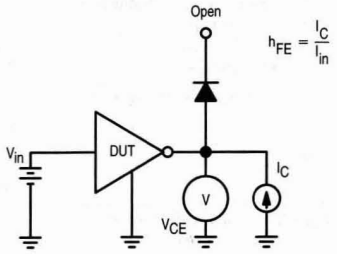



**Figure 3.**

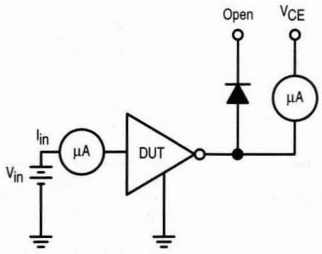



**Figure 4.**

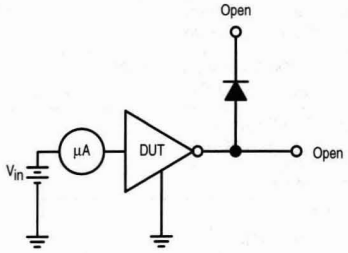



**Figure 5.**

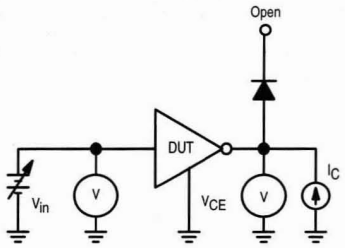



**Figure 6.**

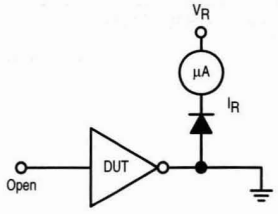
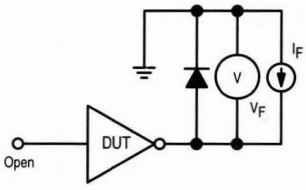



**Figure 7.**



## TYPICAL CHARACTERISTIC CURVES – $T_A$ = 25°C, unless otherwise noted

### Output Characteristics

**Figure 8. Output Current versus Saturation Voltage**

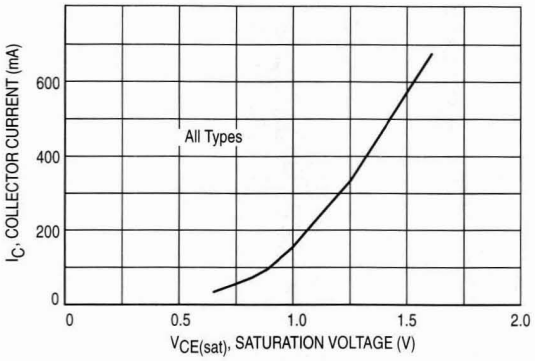
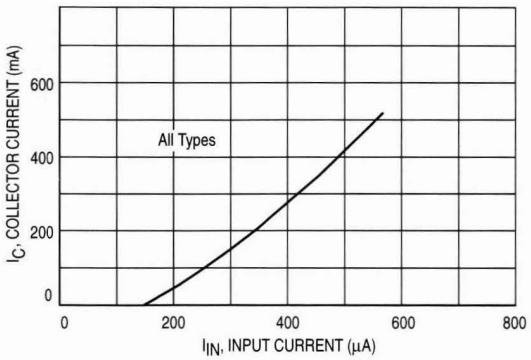



**Figure 9. Output Current versus Input Current**




### Input Characteristics

**Figure 10. ULN2803 Input Current versus Input Voltage**

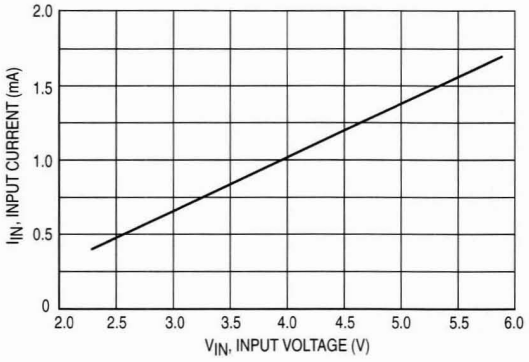



**Figure 11. ULN2804 Input Current versus Input Voltage**

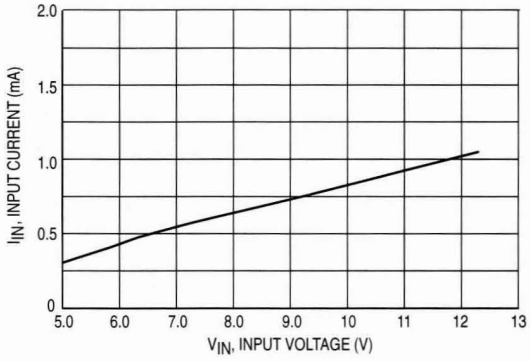
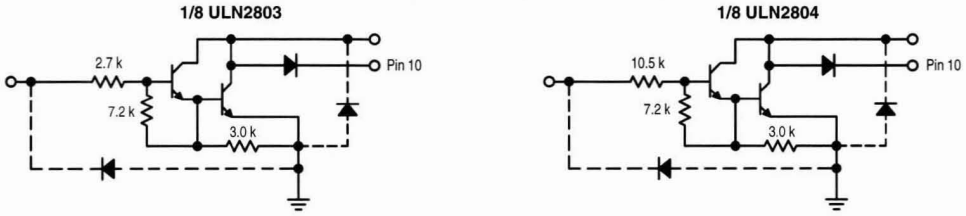



**Figure 12. Representative Schematic Diagrams**



# Communication Circuits

## In Brief . . .

### RF

Radio communication has greatly expanded its scope in the past several years. Once dominated by public safety radio, the 30 to 1000 MHz spectrum is now packed with personal and low cost business radio systems. The vast majority of this equipment uses FM or FSK modulation and is targeted at short range applications. From mobile phones and VHF marine radios to garage door openers and radio controlled toys, these new systems have become a part of our lifestyle. Motorola Analog has focused on this technology, adding a wide array of new products including complete receivers processed in our exclusive 3.0 GHz MOSAIC® 1.5 process. New surface mount packages for high density assembly are available for all of these products, as well as a growing family of supporting application notes and development kits.

### Telephone & Voice/Data

Traditionally, an office environment has utilized two distinctly separate wired communications systems: telecommunications and data communications. Each had its individual hardware components complement, and each required its own independent transmission line system: twisted wire pairs for Telecom and relatively high priced coaxial cable for Datacom. But times have changed. Today, Telecom and Datacom coexist comfortably on inexpensive twisted wire pairs and use a significant number of components in common. This has led to the development and enhancement of PBX (Private Branch Exchanges) to the point where the long heralded "office of the future," with simultaneous voice and data communications capability at each station, is no longer of the future at all. The capability is here today!

Motorola Semiconductor serves a wide range of requirements for the voice/data marketplace. We offer both CMOS and Analog technologies, each to its best advantage, to upgrade the conventional analog voice systems and establish new capabilities in digital communications. Early products, such as the solid–state single–chip crosspoint switch, the more recent monolithic Subscriber–Loop–Interface Circuit (SLIC), a single–chip Codec/Filter (Mono–Circuit), the Universal Digital Loop Transceivers (UDLT), basic rate ISDN (Integrated Services Digital Network), and single–chip telephone circuits are just a few examples of Motorola leadership in the voice/data area.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# RF Communications

## Table 1. RF Front End ICs

| Device | Low Noise Amplifier | | | | Mixer | | | | Voltage Cont Osc | $V_{CC}$ (V) | $I_{CC}$ (mA) | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gain (dB) | Noise Figure (dB) | IIP3 (dBm) | P1dB (dBm) | Gain (dB) | Noise Figure (dB) | IIP3 (dBm) | P1dB (dBm) | | | | |
| MC13141 | 17 | 1.8 | –5 | –15 | 7 | 16 | –3 to +15 | –10 | – | 2.7 to 6.5 | 7.7 | D1/751, D/751A, FTB/976 |
| MC13142 | 17 | 1.8 | –5 | –15 | ±3 | 12 | –3 to +21 | 3 | Yes | 2.7 to 6.5 | 13 | D/751B, FTB/976 |
| MC13143 | – | – | – | – | ±3 | 12 | –3 to +21 | 3 | – | 1.8 to 6.5 | 1 | D/751 |
| MC13144 | 13 to 19 | 1.4 | –1 | –7 | – | – | – | – | – | 1.8 to 6.5 | 2 to 9 | D/751 |

**NOTES:** All devices operate over a wide range of RF input and IF frequencies, from dc to 2.0 GHz.
Typical performance shown at 900 MHz.

## Table 2. Wideband (FM/FSK) IFs

| Device | $V_{CC}$ | $I_{CC}$ | Sensitivity (Typ) | IF | Mute | RSSI | Max Data Rate | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|
| MC13055 | 3–12 V | 25 mA | 20 µV | 40 MHz | ✓ | ✓ | 2.0 Mb | Wideband Data IF, includes data shaper | P/648, D/751B |
| MC13155 | 3–6 V | 7.0 mA | 100 µV | 250 MHz | – | | 10 Mb | Video Speed FM IF | D/751B |

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## Table 3. Wideband Single Conversion Receivers – VHF

| Device | $V_{CC}$ | $I_{CC}$ | Sensitivity (Typ) | RF Input | IF | Mute | RSSI | Max Data Rate | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|---|
| MC3356 | 3–9 V | 25 mA | 30 µV | 200 MHz | 10.7 MHz | ✓ | ✓ | 500 kb | Includes front end mixer/L.O. | P/738, DW/751D |
| MC13156 | 2–6 V | 5.0 mA | 2.0 µV | 500 MHz | 21.4 MHz | – | | | CT–2 FM/Demodulator | DW/751E, FB/873 |
| MC13158 | 2–6 V | 6.0 mA | | | | | | >1.2 Mb | FM IF/Demodulator with split IF for DECT | FTB/873 |
| MC13159 | 2.7–5 V | 5.5 mA | | 600 MHz | | | | 500 kb | FM IF for PHS | DTB/948F |

## Table 4. Narrowband Single Conversion Receivers – VHF

| Device | $V_{CC}$ | $I_{CC}$ | 12 dB SINAD Sensitivity (Typ) | RF Input | IF | Mute | RSSI | Max Data Rate | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|---|
| MC3357 | 4–8 V | 5.0 mA | 5.0 µV | 45 MHz | 455 kHz | ✓ | – | >4.8 kb | Ceramic Quad Detector/Resonator | P/648, D/751B |
| MC3359 | 4–9 V | 7.0 mA | 2.0 µV | | | | | | Scan output option | P/707, DW/751D |
| MC3371 | 2–8 V | 6.0 mA | | 60 MHz | | | ✓ | >4.8 kb | RSSI | P/648, D/751B, DTB/948F |
| MC3372 | | | | | | | | | RSSI, Ceramic Quad Detector/Resonator | |
| MC13150 | 3–6 V | 1.8 mA | 1.0 µV | 500 MHz | | | ✓ 110 dB | >9.6 kb | Coilless Detector with Adjustable Bandwidth | FTB/873, FTA/977 |

## RF Communications (continued)

### Table 5. Narrowband Dual Conversion Receivers – FM/FSK – VHF

| Device | $V_{CC}$ | $I_{CC}$ | 12 dB SINAD Sensitivity (Typ) | RF Input | IF1 | IF2 (Limiter In) | Mute | RSSI | Data Rate | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MC3362 | 2–7 V | 3.0 mA | 0.7 µV | 180 MHz | 10.7 MHz | 455 kHz | – | ✓ | > 4.8 kb | Includes buffered VCO output | P/724, DW/751E |
| MC3363 | | 4.0 mA | 0.4 µV | | | | ✓ | | | Includes RF amp/mute | DW/751F |
| MC3335 | | | 0.7 µV | | | | | | | Low cost version | DW/751D, P/738 |
| MC13135 | | | 1.0 µV | | | | – | | | Voltage buffered RSSI, LC Quad Detector | DW/751E, P/724 |
| MC13136 | | | | | | | | | | Voltage Buffered RSSI, Ceramic Quad Detector | |

### Table 6. Universal Cordless Phone Subsystem ICs

| Device | $V_{CC}$ | $I_{CC}$ | Dual Conversion Receiver | Universal Dual PLL | Compander and Audio Interface | Voice Scrambler | Low Battery Detect | Programmable $R_X$, $T_X$ Trim Gain and LBD Voltage Reference | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|
| MC13109 | 2.0–5.5 V | Active Mode 6.7 mA Inactive Mode 40 µA | ✓ | ✓ | ✓ | – | 1 | – | FB/848B, FTA/932 |
| MC13110 | 2.7–5.5 V | Active Mode 8.2 mA Inactive Mode 60 µA | ✓ | ✓ | ✓ | ✓ | 2 | ✓ | FB/848B |
| MC13111 | 2.7–5.5 V | Active Mode 8.2 mA Inactive Mode 60 µA | ✓ | ✓ | ✓ | – | 2 | ✓ | FB/848B |

### Table 7. Transmitters – AM/FM/FSK

| Device | $V_{CC}$ | $I_{CC}$ | $P_{out}$ | Max RF Freq Out | Max Mod Freq | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|
| MC2833 | 3–8 V | 10 mA | –30 dBm to +10 dBm | 150 MHz | 50 kHz | FM transmitter. Includes two frequency multiplier/amplifier transistors | P/648, D/751B |
| MC13175 | 2–5 V | 40 mA | 8.0 dBm | 500 MHz | 5.0 MHz | AM/FM transmitter. Single frequency PLL $f_{out} = 8 \times f_{ref}$, includes power down function | D/751B |
| MC13176 | | | | 1.0 GHz | | $f_{out} = 32 \times f_{ref}$, includes power down function | |

8

**Table 8. Balanced Modulator/Demodulator**

| Device | $V_{CC}$ | $I_{CC}$ | Function | Suffix/ Package |
|---|---|---|---|---|
| MC1496 | 3–5 V | 10 mA | General purpose balanced modulator/demodulator for AM, SSB, FM detection with Carrier Balance >50 dB | P/646, D/751A |

**Table 9. Infrared Transceiver**

| Device | $V_{CC}$ | $I_{CC}$ | 12 dB SINAD Sensitivity (Typ) | Max IF Freq | Carr Det | RSSI | Data Rate | Notes | Suffix/ Package |
|---|---|---|---|---|---|---|---|---|---|
| MC13173 | 3–5 V | 6.5 mA | 5.0 μV | 10.7 MHz | ✓ | ✓ | 200 kb | Includes Single Frequency PLL for $T_X$ Carrier and $R_X$ $L_O$ | FTB/873 |

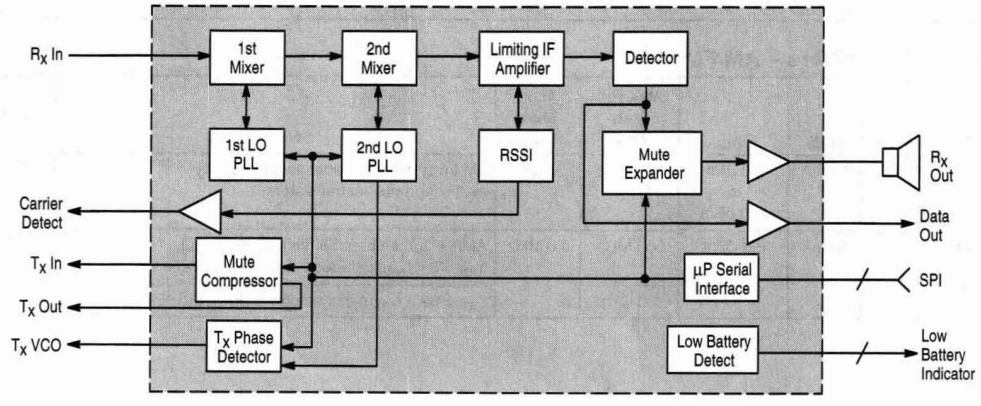
# Universal Cordless Telephone Subsystem IC

**MC13109FB, FTA**

$T_A$ = −20° to +85°C, Case 848B, 932

The MC13109 integrates several of the functions required for a cordless telephone into a single integrated circuit. This significantly reduces component count, board space requirements, and external adjustments. It is designed for use in both the handset and the base.

- Dual Conversion FM Receiver
  - Complete Dual Conversion Receiver – Antenna Input to Audio Output 80 MHz Maximum Carrier Frequency
  - RSSI Output
  - Carrier Detect Output with Programmable Threshold
  - Comparator for Data Recovery
  - Operates with Either a Quad Coil or Ceramic Discriminator
- Compander
  - Expandor Includes Mute, Digital Volume Control and Speaker Driver
  - Compressor Includes Mute, ALC and Limiter
- Dual Universal Programmable PLL
  - Supports New 25 Channel U.S. Standard with No External Switches
  - Universal Design for Domestic and Foreign CT–1 Standards
  - Digitally Controlled Via a Serial Interface Port
  - Receive Side Includes 1st LO VCO, Phase Detector, and 14–Bit Programmable Counter and 2nd LO with 12–Bit Counter
  - Transmit Section Contains Phase Detector and 14–Bit Counter
  - MPU Clock Output Eliminates Need for MPU Crystal
- Supply Voltage Monitor
  - Externally Adjustable Trip Point
- 2.0 to 5.5 V Operation with One–Third the Power Consumption of Competing Devices



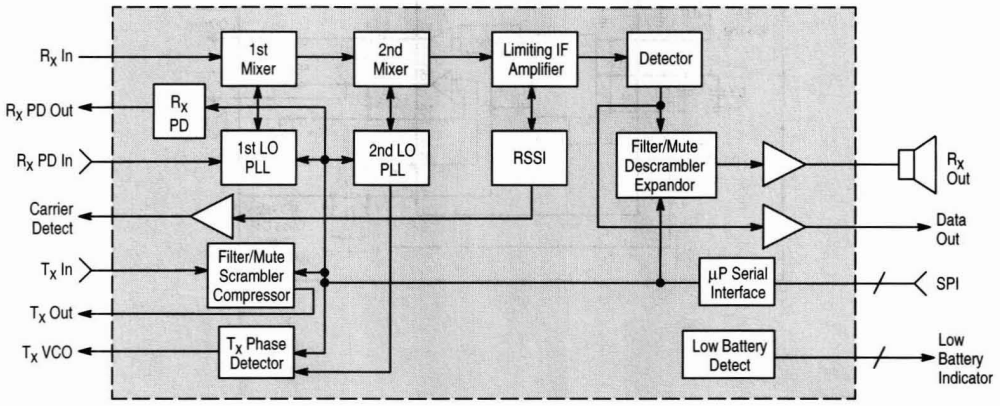
# Universal Cordless Telephone Subsystem IC with Scrambler

**MC13110FB**

$T_A$ = –40° to +85°C, Case 848B

The MC13110 integrates several of the functions required for a cordless telephone into a single integrated circuit. This significantly reduces component count, board space requirements, and external adjustments. It is designed for use in both the handset and the base.

- Dual Conversion FM Receiver
  - Complete Dual Conversion Receiver – Antenna In to Audio Out 80 MHz Maximum Carrier Frequency
  - RSSI Output
  - Carrier Detect Output with Programmable Threshold
  - Comparator for Data Recovery
  - Operates with Either a Quad Coil or Ceramic Discriminator
- Compander
  - Expandor Includes Mute, Digital Volume Control, Speaker Driver, 3.5 kHz Low Pass Filter, and Programmable Gain Block
  - Compressor Includes Mute, 3.5 kHz Low Pass Filter, Limiter, and Programmable Gain Block
- Dual Universal Programmable PLL
  - Supports New 25 Channel U.S. Standard with New External Switches
  - Universal Design for Domestic and Foreign CT–1 Standards
  - Digitally Controlled Via a Serial Interface Port
  - Receive Side Includes 1st LO VCO, Phase Detector, and 14–Bit Programmable Counter and 2nd LO with 12–Bit Counter
  - Transmit Section Contains Phase Detector and 14–Bit Counter
  - MPU Clock Outputs Eliminates Need for MPU Crystal
- Supply Voltage Monitor
  - Provides Two Levels of Monitoring with Separate Outputs
  - Separate, Adjustable Trip Points
- Frequency Inversion Scrambler/Descrambler
  - Can Be Enabled/Disabled Via MPU Interface
  - Programmable Carrier Modulation Frequency
- 2.7 to 5.5 V Operation with One–Third the Power Consumption of Competing Devices




8

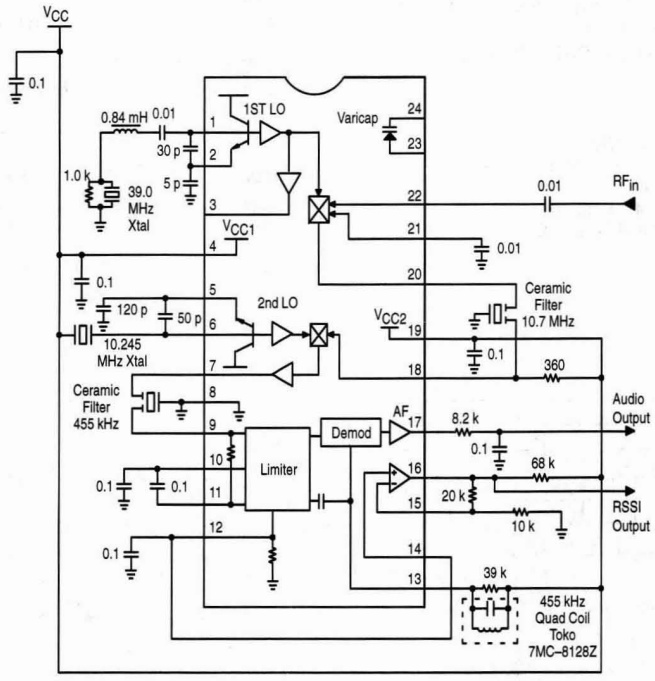
# Narrowband FM Receiver

**MC13135/136P, DW**

$T_A$ = –40° to +85°C, Case 724, 751E

The MC13135 is a full dual conversion receiver with oscillators, mixers, Limiting IF Amplifier, Quadrature Discriminator, and RSSI circuitry. It is designed for use in security systems, cordless phones, and VHF mobile and portable radios. Its wide operating supply voltage range and low current make it ideal for battery applications. The Received Signal Strength Indicator (RSSI) has 65 dB of dynamic range with a voltage output, and an operational amplifier is included for a dc buffered output. Also, an improved mixer third order intercept enables the MC13135 to accommodate larger input signal levels.

- Complete Dual Conversion Circuitry
- Low Voltage: 2.0 to 6.0 Vdc
- RSSI with Op Amp: 65 dB Range
- Low Drain Current: 3.5 mA Typical
- Improved First and Second Mixer 3rd Order Intercept
- Detector Output Impedance: 25 Ω Typically



# Narrowband FM Coilless Detector IF Subsystem

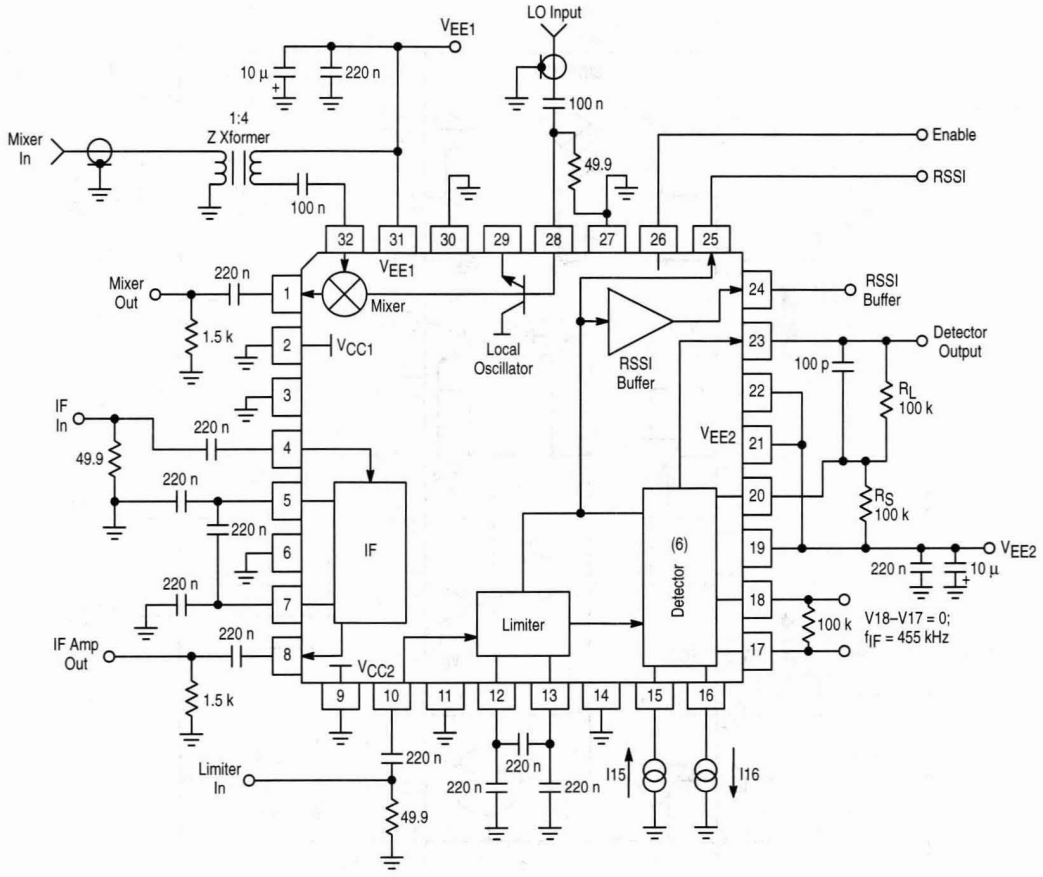
**MC13150FTA, FTB**

$T_A$ = –40° to +85°C, Case 977, 873

The MC13150 is a narrowband FM IF subsystem targeted at cellular and other analog applications. Excellent high frequency performance is achieved, with low cost, through use of Motorola's MOSAIC 1.5™ RF bipolar process. The MC13150 has an onboard Colpitts VCO for Crystal controlled second LO in dual conversion receivers. The mixer is a double balanced configuration with excellent third order intercept. It is useful to beyond 200 MHz. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. The quadrature detector is a unique design eliminating the conventional tunable quadrature coil.

Applications for the MC13150 include cellular, CT–1 900 MHz cordless telephone, data links and other radio systems utilizing narrowband FM modulation.

- Linear Coilless Detector
- Adjustable Demodulator Bandwidth
- 2.5 to 6.0 Vdc Operation
- Low Drain Current: < 2.0 mA
- Typical Sensitivity of 2.0 μV for 12 dB SINAD
- IIP3, Input Third Order Intercept Point of 0 dBm
- RSSI Range of Greater Than 100 dB
- Internal 1.4 kΩ Terminations for 455 kHz Filters
- Split IF for Improved Filtering and Extended RSSI Range




8

# Wideband FM IF System

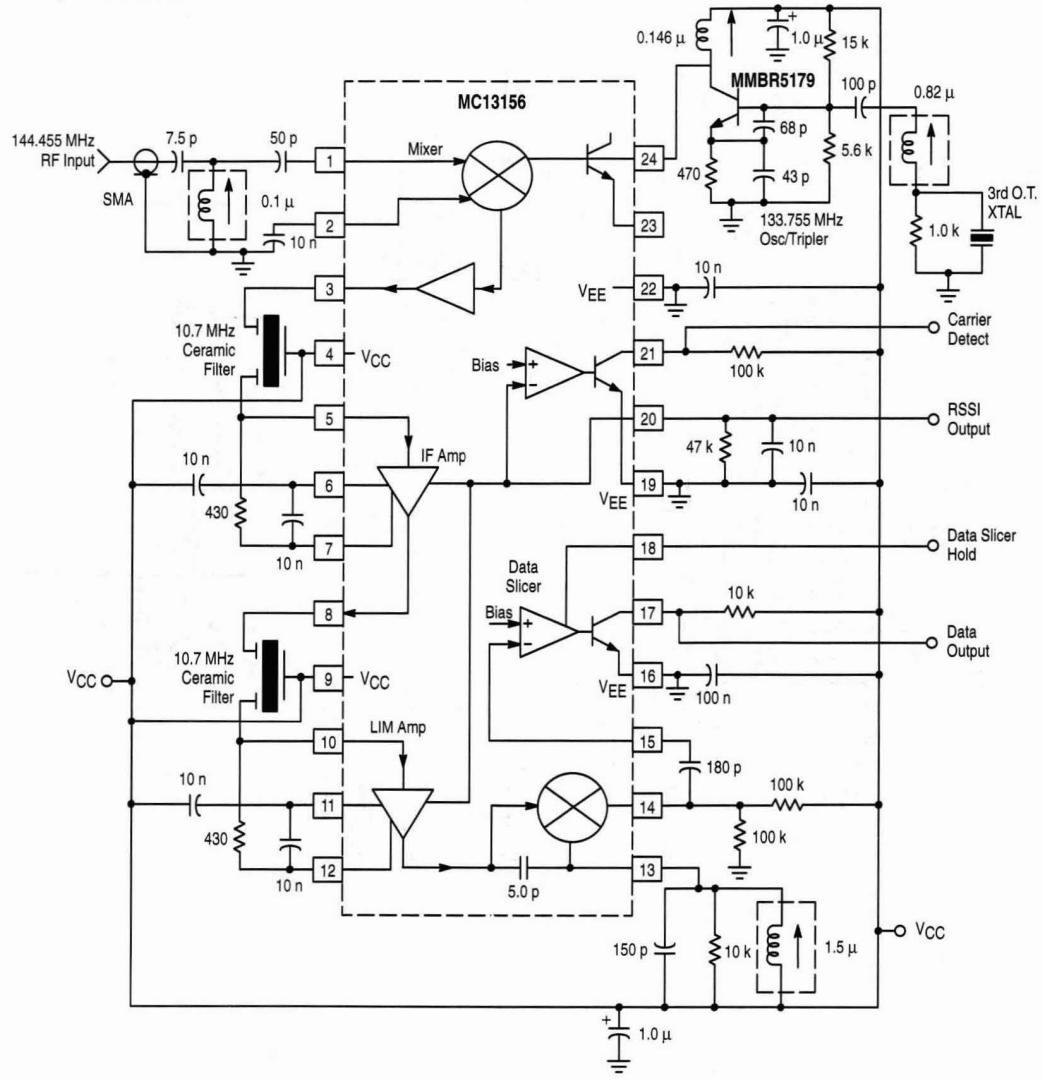
**MC13156DW, FB**

$T_A$ = –40° to +85°C, Case 751E, 873

The MC13156 is a wideband FM IF subsystem targeted at high performance data and analog applications. Excellent high frequency performance is achieved, with low cost, through use of Motorola's MOSAIC 1.5™ RF bipolar process. The MC13156 has an onboard Colpitts VCO for PLL controlled multichannel operation. The mixer is useful to beyond 200 MHz and may be used in a differential, balanced, or single–ended configuration. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. A precision data shaper has a hold function to preset the shaper for fast recovery of new data.

Applications for the MC13156 include CT–2, wideband data links, and other radio systems utilizing GMSK, FSK or FM modulation.

- 2.0 to 6.0 Vdc Operation
- Typical Sensitivity of 6.0 μV for 12 dB SINAD
- RSSI Dynamic Range Typically 80 dB
- High Performance Data Shaper for Enhanced CT–2 Operation
- Internal 300 Ω and 1.4 kΩ Terminations for 10.7 MHz and 455 kHz Filters
- Split IF for Improved Filtering and Extended RSSI Range



# Wideband FM IF Subsystem

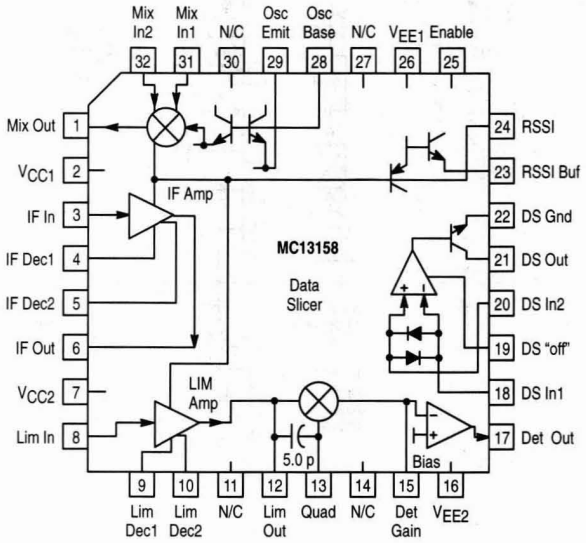
**MC13158FTB**

$T_A$ = –40° to +85°C, Case 873

The MC13158 is a wideband IF subsystem that is designed for high performance data and analog applications. Excellent high frequency performance is achieved, with low cost, through the use of Motorola's MOSAIC 1.5™ RF bipolar process. The MC13158 has an on–board grounded collector VCO transistor that may be used with a fundamental or overtone crystal in single channel operation or with a PLL in multi–channel operation. The mixer is useful to 500 MHz and may be used in a balanced differential or single ended configuration. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. A precision data shaper has an Off function to shut the output "off" to save current. An enable control is provided to power down the IC for power management in battery operated applications.

Applications include DECT, wideband wireless data links for personal and portable laptop computers and other battery operated radio systems which utilize GFSK, FSK or FM modulation.

- Designed for DECT Applications
- 1.8 to 6.0 Vdc Operating Voltage
- Low Power Consumption in Active and Standby Mode
- Greater than 600 kHz Detector Bandwidth
- Data Slicer with Special Off Function
- Enable Function for Power Down of Battery Operated Systems
- RSSI Dynamic Range of 80 dB Minimum
- Low External Component Count




8

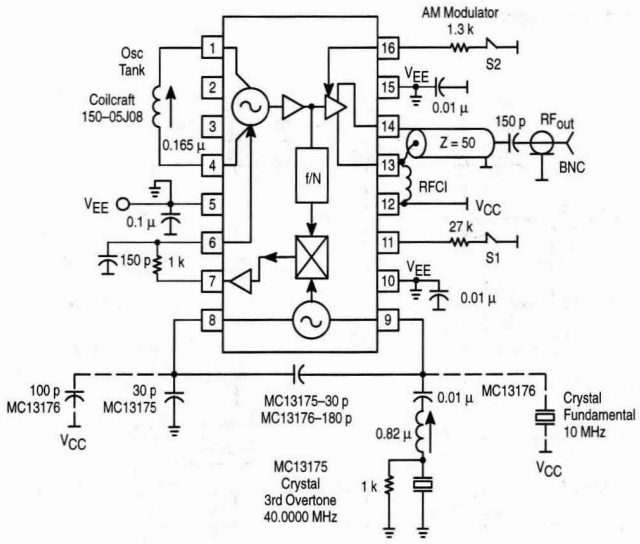
# UHF, FM/AM Transmitter

**MC13175/176D**

$T_A$ = 0° to +70°C, Case 751B

The MC13175 and MC13176 are one chip FM/AM transmitter subsystems designed for AM/FM communication systems operating in the 260 to 470 MHz band covered by FCC Title 47; Part 15. They include a Colpitts crystal reference oscillator, UHF oscillator, ÷8 (MC13175) or ÷32 (MC13176) prescaler, and phase detector forming a versatile PLL system. Another application is as a local oscillator in a UHF or 900 MHz receiver. MC13175/176 offer the following features:

- UHF Current Controlled Oscillator
- Use Easily Available 3rd Overtone or Fundamental Crystals for Reference
- Low Number of External Parts Required
- Low Operating Supply Voltage (1.8–5 Vdc)
- Low Supply Drain Currents
- Power Output Adjustable (Up to +10 dBm)
- Differential Output for Loop Antenna or Balun Transformer Networks
- Power Down Feature
- ASK Modulated by Switching Output "On"/"Off"
- MC13175 – $f_O = 8 \times f_{ref}$
- MC13176 – $f_O = 32 \times f_{ref}$




8

# Telecommunications

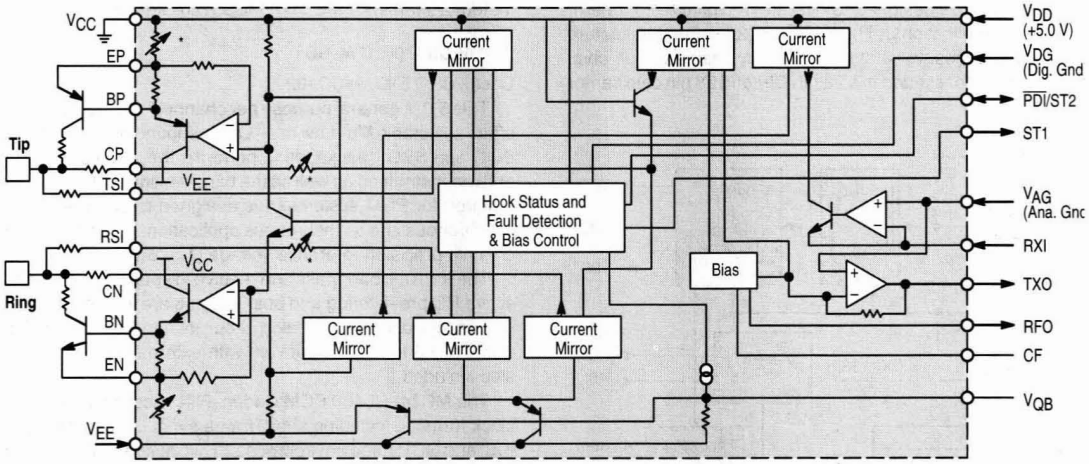
## Subscriber Loop Interface Circuit (SLIC)

**MC33120/1P, FN**

$T_A$ = –40° to +85°C, Case 738, 776

With a guaranteed minimum longitudinal balance of 58 dB, the MC33120/1 is ideally suited for Central Office applications, as well as PBXs, and other related equipment. Protection and sensing components on the two–wire side can be non–precision while achieving required system performance. Most BORSHT functions are provided while maintaining low power consumption, and a cost effective design. Size and weight reduction over conventional transformer designs permit a higher density system.

- All Key Parameters Externally Programmable with Resistors:
  - Transmit and Receive Gains
  - Transhybrid Loss
  - Return Loss
  - DC Loop Current Limit and Battery Feed Resistance
  - Longitudinal Impedance
- Single and Double Fault Sensing and Protection
- Minimum 58 dB Longitudinal Balance (2–wire and 4–wire) Guaranteed
- Digital Hook Status and Fault Outputs
- Power Down Input
- Loop Start or Ground Start Operation
- Size & Weight Reduction Over Conventional Approaches
- Available in 20 Pin DIP and 28 Pin PLCC Packages
- Battery Voltage: –42 to –58 V (for MC33120), –21.6 to –42 V (for MC33121)




* Indicates Trimmed Resistor

8

# PBX Architecture (Analog Transmission)

## PCM Mono–Circuits Codec–Filters (CMOS LSI)

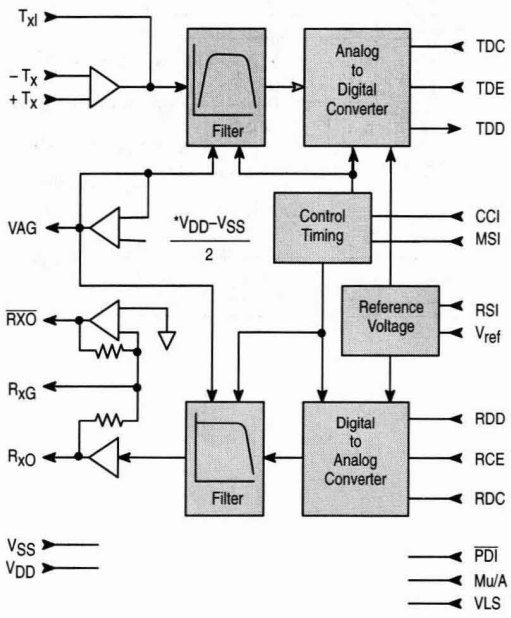
### MC145500 Series

Case 648, 708, 751G, 776

The Mono–circuits perform the digitizing and restoration of the analog signals. In addition to these important functions, Motorola's family of pulse–code modulation mono–circuits also provides the band–limiting filter functions – all on a single monolithic CMOS chip with extremely low power dissipation.

The Mono–circuits require no external components. They incorporate the bandpass filter required for antialiasing and 60 Hz rejection, the A/D–D/A conversion functions for either U.S. Mu–Law or European A–Law companding formats, the low–pass filter required for reconstruction smoothing, an on–board precision voltage reference, and a variety of options that lend flexibility to circuit implementations. Unique features of Motorola's Mono–circuit family include wide power supply range (6.0 to 13 V), selectable on–board voltage reference (2.5, 3.1, or 3.8 V), and TTL or CMOS I/O interface.

Motorola supplies three versions in this series. The MC145503 and MC145505 are general–purpose devices in 16 pin packages designed to operate in digital telephone or line card applications. The MC145502 is the full–feature device that presents all of the options available on the chip. This device is packaged in a 22 pin DIP and 28 pin chip carrier package.




### MC145554/57/64/67

Case 648, 751D, 751G, 738

These per channel PCM Codec–Filters perform the voice digitization and reconstruction as well as the band limiting and smoothing required for PCM systems. They are designed to operate in both synchronous and asynchronous applications and contain an on–chip precision voltage reference. The MC145554 (Mu–Law) and MC145557 (A–Law) are general purpose devices that are offered in 16 pin packages. The MC145564 (Mu–Law) and MC145567 (A–Law), offered in 20 pin packages, add the capability of analog loop–back and push–pull power amplifiers with adjustable gain.

All four devices include the transmit bandpass and receive lowpass filters on–chip, as well as active RC pre–filtering and post–filtering. Fully differential analog circuit design assures lowest noise. Performance is specified over the extended temperature range of –40° to +85°C.

These PCM Codec–Filters accept both industry standard clock formats. They also maintain compatibility with Motorola's family of MC3419/MC33120 SLIC products.

### MC14LC5480P, DW, SD

Case 738, 751D, 940C–02

This 5.0 V, general purpose per channel PCM Codec–Filter offers selectable Mu–Law or A–Law companding in 20 pin DIP, SOG and SSOP packages. It performs the voice digitization and reconstruction as well as the band limiting and smoothing required for PCM systems. It is designed to operate in both synchronous and asynchronous applications and contains an on–chip precision reference voltage (1.575 V).

The transmit bandpass and receive lowpass filters, and the active RC pre–filtering and post–filtering are incorporated, as well as fully differential analog circuit design for lowest noise. Push–pull 300 Ω power drivers with external gain adjust are also included.

The MC14LC5480 PCM Codec–Filter accepts a variety of clock formats, including short–frame sync, long–frame sync, IDL, and GCI timing environments. This device also maintains compatibility with Motorola's family of Telecom products, including the MC145472 U–Interface Transceiver, MC145474/75 S/T–Interface Transceiver, MC145532 ADPCM Transcoder, MC145422/26 UDLT–I, MC145421/25 UDLT–II, and MC3419/MC33120 SLIC.

Replaces the MC145480P, DW, SD.

## PBX Architecture (continued)

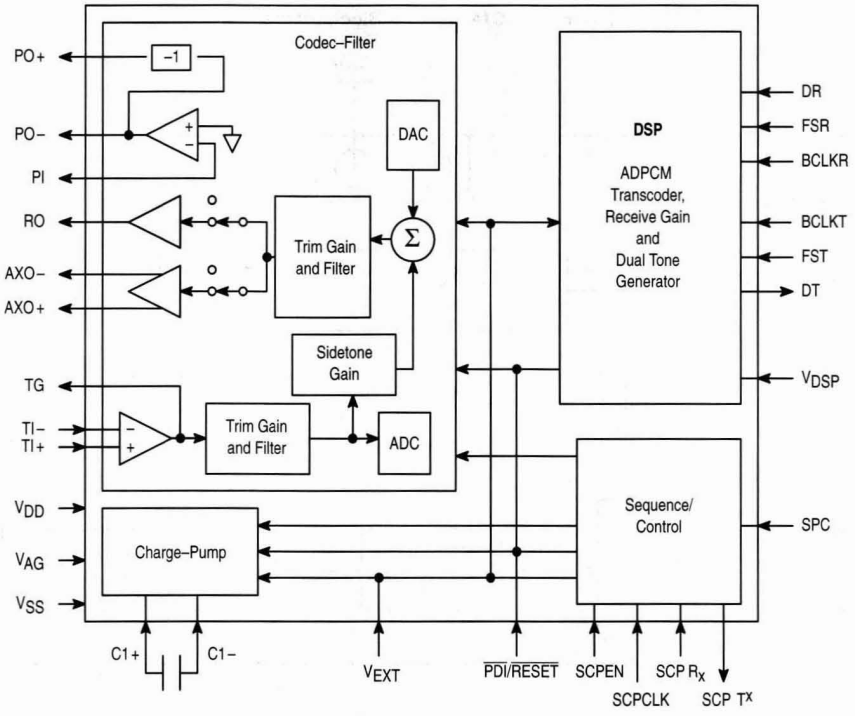
**MC14LC5540P, DW, FU**

Case 710, 751F, 873

The MC14LC5540 ADPCM Codec is a single chip implementation of a PCM Codec–Filter and an ADPCM encoder/decoder, and therefore provides an efficient solution for applications requiring the digitization and compression of voiceband signals. This device is designed to operate over a wide voltage range, 2.7 V to 5.25 V, and as such is ideal for battery powered as well as ac powered applications. The MC14LC5540 ADPCM Codec also includes a serial control port and internal control and status registers that permit a microcomputer to exercise many built–in features.

The ADPCM Codec is designed to meet the 32 kbps ADPCM conformance requirements of CCITT Recommendation G.721 (1988) and ANSI T1.301 (1987). It also meets ANSI T1.303 and CCITT Recommendation G.723 for 24 kbps ADPCM operation, and the 16 kbps ADPCM standard, CCITT Recommendation G.726. This device also meets the PCM conformance specification of the CCITT G.714 Recommendation.

**Figure 1. MC14LC5540 ADPCM Codec Block Diagram**




8

## PBX Architecture (continued)

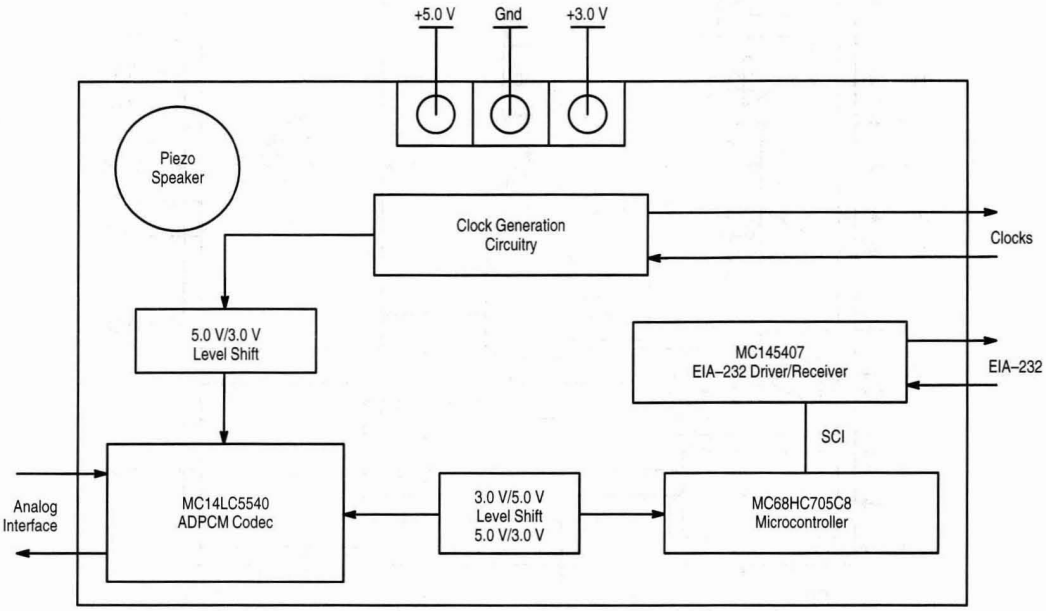
**MC145537EVK**

ADPCM Codec Evaluation Kit

The MC145537EVK is the primary tool for evaluation and demonstration of the MC14LC5540 ADPCM Codec. It provides the necessary hardware and software interface to access the many features and operational modes of the MC14LC5540 ADPCM Codec.

- Provides Stand Alone Evaluation on Single Board
- The kit provides Analog–to–Analog, Analog–to–Digital or Digital–to–Analog Connections – with Digital Connections being 64 kbps PCM, 32 or 24 kbps ADPCM, or 16 kbps CCITT G.726 or Motorola Proprietary ADPCM
- +5.0 V Only Power Supply, or 5.0 V Plus 2.7 to 5.25 V Supply
- Easily Interfaced to Test Equipment, Customer System, Second MC145537EVK or MC145536EVK (5.0 V Only) for Full Duplex Operation
- Convenient Access to Key Signals
- Piezo Loudspeaker
- EIA–232 Serial Computer Terminal Interface for Control of the MC14LC5540 ADPCM Codec Features
- Compatible Handset Provided
- Schematics, Data Sheets, and User's Manual Included

**Figure 2. MC145537EVK Block Diagram**

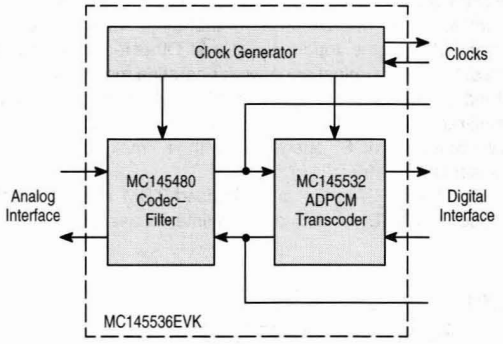


**MC145536EVK**

Codec–Filter/ADPCM Transcoder Evaluation Kit

The MC145536EVK is the primary tool for evaluation and demonstration of the MC14LC5480 Single +5.0 V supply PCM Codec–Filter and the MC145532 ADPCM Transcoder (see "Telephone Accessory Circuits"). The MC145536EVK provides the necessary hardware needed to evaluate the many separate operating modes under which the MC14LC5480 and MC145532 are intended to operate.

- Provides Stand Alone Evaluation on a Single Board
- Easily Interfaced to Test Equipment, Customer System, or Second MC145536EVK
- Convenient Access to Key Signals
- Generous Wire–Wrap Area for Application Development
- The kit provides Analog–to–Analog, Analog–to–Digital, or Digital–to–Analog Connections – with Digital Connections Being 64 kbps PCM; 32, 24, or 16 kbps Motorola Proprietary ADPCM
- Compatible Handset Included
- Schematics, Data Sheets, and User's Manual included




## Dual Tone Multiple Frequency Receiver

**MC145436AP, DW**

Case 646, 751G

This device contains the filter and decoder for detection of a pair of tones conforming to the DTMF standard with outputs in hexadecimal. Switched capacitor filter technology is used together with digital circuitry for the timing control and output circuits. The MC145436A provides excellent power–line noise and dial tone rejection.

Replaces MC145436P, DW.

# ISDN Voice/Data Circuits

## Integrated Services Digital Network

ISDN is the revolutionary concept of converting the present analog telephone networks to an end–to–end global digital network. ISDN standards make possible a wide variety of services and capabilities that are revolutionizing communications in virtually every industry.

Motorola's ISDN product family includes the MC14LC5472 and MC145572 U–Interface Transceivers, the MC145474/75 and MC145574 S/T–Interface Transceivers, MC145488 Dual Data Link Controller, and the MC68302 Integrated Multi–Protocol Processor. These are supported by a host of related devices including the MC14LC5480 +5.0 V PCM Codec–Filter, MC145532 ADPCM Transcoder, MC14LC5540 ADPCM Codec, MC145500 family of single–chip codec/filters, MC145436A DTMF Decoder, MC33120 Subscriber Loop Interface Circuit, MC34129 Switching Power Supply Controller, and the MC145406/07 CMOS EIA 232–E Driver/ Receiver family.

Motorola's key ISDN devices fit into four ISDN network applications: a digital subscriber line card, an NT1 network termination, an ISDN terminal adapter, and an ISDN terminal. Digital subscriber line cards are used in central offices, remote concentrators, channel banks, T1 multiplexers, and other switching equipment. The NT1 network termination block illustrates the simplicity of remote U– to S/T–interface conversion. The ISDN terminal adapter and ISDN terminal block show how Motorola ICs are used to combine voice and data in PC compatible boards, digital telephones, and other terminal equipment. Expanded applications such as a PBX may include these and other Motorola ISDN circuits. Many "non–ISDN" uses, such as pairgain applications, are appropriate for Motorola's ISDN devices as well.

## Second Generation U–Interface Transceivers

**MC145572PB**

Case 842D

**MC145572FN**

Case 777

The MC145572 fully conforms to ANSI T1.601–1992, the North American standard for ISDN Basic Access on a single twisted–wire pair. The transceiver achieves a remarkable $10^{-7}$ bit error rate performance on all ANSI specified test loops with worst–case impairments present. The state–of–the–art 0.65 micron single–chip solution uses advanced design techniques to combine precision analog signal processing elements with three digital signal coprocessors to build an adaptively equalized echo cancelling receiver.

Two modes of handling U–interface maintenance functions are provided on the MC145572. In the automatic maintenance mode the U–interface transceiver handles all ANSI specified maintenance and channel procedures internally to minimize your software development effort. Automatic procedures include generating and monitoring the cyclic redundancy check, reporting and counting far end block errors (near end block errors too), handling the ACT and DEA bits, as well as monitoring and appropriately responding to embedded operations channel messages.

The MC145572 has 275 mW maximum power dissipation. It also has an enhanced TDM interface that supports an on–chip timeslot assigner, GCI and IDL modes of operation.

The optional manual maintenance mode lets you choose an inexpensive microcontroller, such as a member of Motorola's MC68HC05 family, to control and augment the standard maintenance channel functions. This flexible feature also allows for easy implementation of proprietary maintenance functions.

## Second Generation S/T–Interface Transceivers

**MC145574PB**

Case 873A

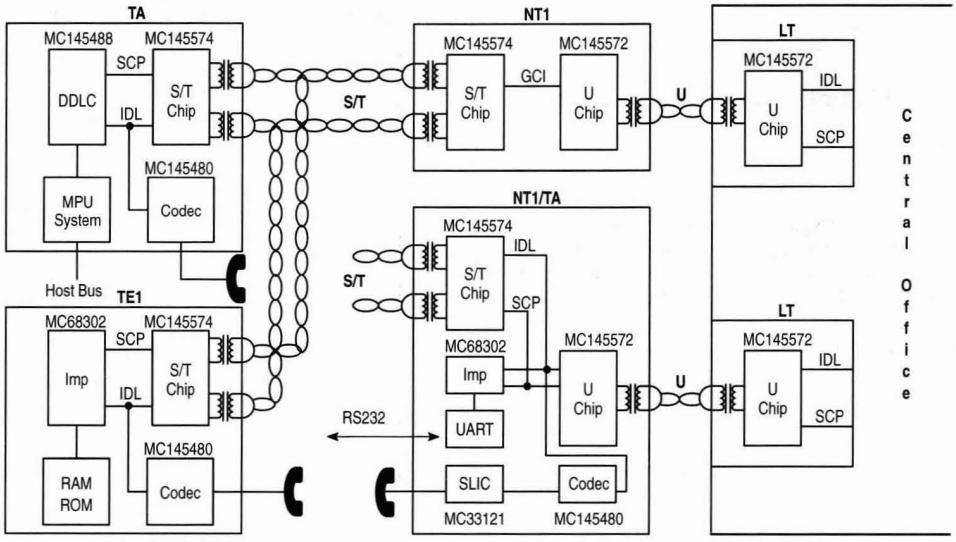
**MC145574DW**

Case 751F

The MC145574 S/T–Interface Transceivers provide a CCITT I.430 compatible interface for use in line card, network termination, and ISDN terminal equipment applications. Manufactured with Motorola's advanced 0.65 micron CMOS mixed analog and digital process technology, the MC145574 is a physical layer device capable of operating in point–to–point or point–to–multipoint passive bus arrangements. In addition, the MC145574 implements the optional NT1 Star topology, NT terminal mode and TE slave mode.

This device features outstanding transmission performance. It reliably transmits over 1 kilometer in a point–to–point application. Comparable performance is achieved in all other topologies as well. Other features include pin selectable terminal or network operating modes, industry standard microprocessor serial control port, full support of the multiframing S and Q channels, a full range of loopbacks, and low power CMOS operation, with a maximum power consumption of 90 mW.

The MC145574 has an enhanced TDM interface that supports GCI, IDL and an on–chip timeslot assigner.



## Dual Data Link Controller

**MC145488FN**
Case 779

The MC145488 features two full–duplex serial HDLC channels with an on–chip Direct Memory Access (DMA) controller. The DMA controller minimizes the number of microprocessor interrupts from the communications channels, freeing the microprocessor's resources for other tasks. The DMA controller can access up to 64 kbytes of memory, and transfers either 8–bit bytes or 16–bit words to or from memory. The MC145488 DDLC is compatible with Motorola's MC68000 and other microprocessors.

In a typical ISDN terminal application, one DDLC communications channel supports the D–channel (LAPD) while the other supports the B–channel (LAPB). While the DDLC is ideally suited for ISDN applications, it can support many other HDLC protocol applications as well.

Some of the powerful extras found on the DDLC include automatic abort and retransmit of D–channel collisions in S/T–interface applications, address recognition, automatic recovery mechanisms for faulty frame correction, and several system test modes. Address recognition provides a reduction in the host microprocessor load by filtering data frames not addressed to the host. The DDLC can compare either SAPI or TEI fields of LAPD frames. For LAPD (Q.921) applications, both A and B addresses may be checked.

**MC14LC5494EVK**
U–Interface Transceiver Evaluation Kit discontinued

**MC145572EVK**
U–Interface Transceiver Evaluation Kit

This kit provides the hardware and software to evaluate the many configurations under which the MC145572EVK is able to operate. Used as a whole, it operates as both ends of the two–wire U interface that extends from the customer premises (NT1) to the switch line card (LT). The two halves of the board can be physically and functionally separated, providing independent NT1 and LT evaluation capability.

The kit provides the ability to interactively manipulate status registers in the MC145572EVK U–Interface transceiver or in the MC145474/75 S/T–Interface transceiver with the aid of an external terminal. The device can also be controlled using the MC68302 Integrated Multiprotocol Processor application development system to complete a total Basic Rate ISDN evaluation solution.

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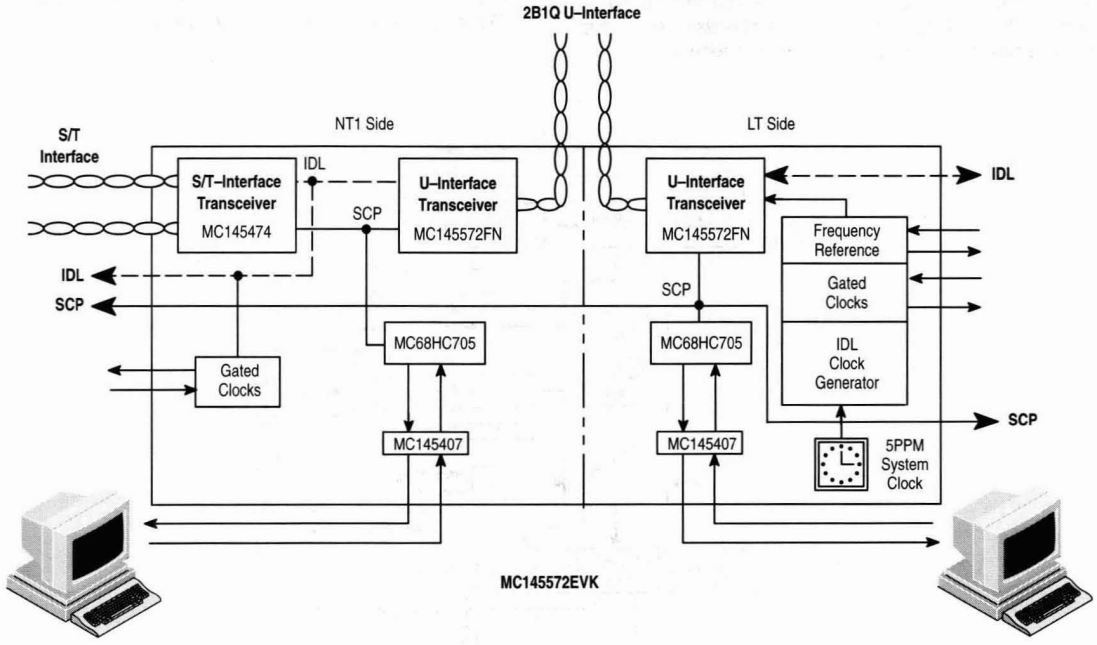


# Voice/Data Communication (Digital Transmission)

## 2–Wire Universal Digital Loop Transceiver (UDLT)

**MC145422P, DW Master Station**

Case 708, 751E

**MC145426P, DW Slave Station**

Case 708, 751E

The UDLT family of transceivers allows the use of existing twisted–pair telephone lines (between conventional telephones and a PBX) for the transmission of digital data. With the UDLT, every voice–only telephone station in a PBX system can be upgraded to a digital telephone station that handles the complex voice/data communications with no increase in cabling costs.

In implementing a UDLT–based system the A/D to D/A conversion function associated with each telset is relocated from the PBX directly to the telset. The SLIC (or its equivalent circuit) is eliminated since its signaling information is transmitted digitally between two UDLTs.

The UDLT master–slave system incorporates the modulation/demodulation functions that permit data communications over a distance up to 2 kilometers. It also provides the sequence control that governs the exchange of information between master and slave. Specifically, the master resides on the PBX line card where it transmits and receives data over the wire pair to the telset. The slave is located in the telset and interfaces the mono–circuit to the wire pair. Data transfer occurs in 10–bit bursts (8 bits of data and 2 signaling bits), with the master transmitting first, and the slave responding in a synchronized half–duplex transmission format.

UDLTs utilize a 256 kilobaud Modified Differential Phase Shift Keyed (MDPSK) burst modulation technique for transmission to minimize radio frequency, electromagnetic, and crosstalk interference. Implementation through CMOS technology takes advantage of low–power operation, increased reliability, and the proven capabilities to perform complex telecommunications functions.

**Functional Features**

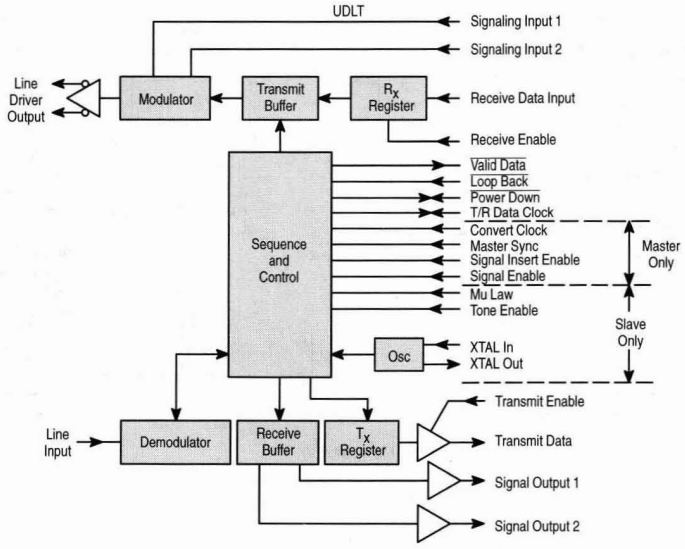
- Provides Synchronous Duplex 64 kbits/Second Voice/Data Channel and Two 8 kbits/Second Signaling Data Channels Over One 26 AWG Wire Pair Up to 2 km.
- Compatible with Existing and Evolving Telephone Switch Architectures and Call Signaling Schemes
- Automatic Detection Threshold Adjustment for Optimum Performance Over Varying Signal Attenuations
- Protocol Independent
- Single 5.0 V to 8.0 V Power Supply

**MC145422 Master UDLT**

- 2.048 MHz Master Clock
- Pin Controlled Power–Down and Loop–Back Features
- Variable Data Clock – 64 kHz to 2.56 MHz
- Pin Controlled Insertion/Extraction of 8 kbits/Seconds Channel into LSB of 64 kbits/Second Channel for Simultaneous Routing of Voice and Data Through PCM Voice Path of Telephone Switch

**MC145426 Slave UDLT**

- Compatible with MC145500 Series and Later PCM Mono–Circuits
- Automatic Power–Up/Down Feature
- On–Chip Data Clock Recovery and Generation
- Pin Controlled 500 Hz D3 or CCITT Format PCM Tone Generator for Audible Feedback Applications



## 2–Wire ISDN Universal Digital Loop Transceiver II (UDLT II)

**MC145421P, DW Master**

Case 709, 751E

**MC145425P, DW Slave**

Case 709, 751E

Similar to the MC145422/26 UDLT, but provide synchronous full duplex 160 kbps voice and data communication in a 2B + 2D format for ISDN compatibility on a single twisted pair up to 1 km. Single 5.0 V power supply, protocol independent.

# Electronic Telephone

## The Complete Electronic Telephone Circuit

**MC34010P, FN**

$T_A$ = –20° to +60°C, Case 711, 777

The conventional transformer–driven telephone handset is undergoing major innovations. The bulky transformer is disappearing. So are many of its discrete components, including the familiar telephone bell. They are being replaced with integrated circuits that perform all the major handset functions simply, reliably and inexpensively . . . functions such as 2–to–4 wire conversion, DTMF dialing, tone ringing, and a variety of related activities.

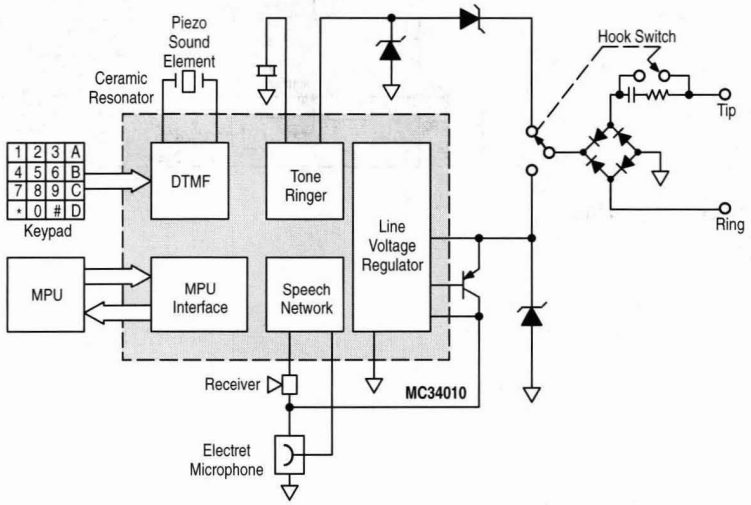
The culmination of these capabilities is the Electronic Telephone Circuit, the MC34010. These ICs place all of the above mentioned functions on a single monolithic chip.

These telephone circuits utilize advanced bipolar analog ($I^2L$) technology and provide all the necessary elements of a modern tone–dialing telephone. The MC34010 even incorporates an MPU interface circuit for the inclusion of automatic dialing in the final system.

- Provides all basic telephone functions, including DTMF dialer, tone ringer, speech network and line voltage regulator
- DTMF generator uses low cost ceramic resonator with accurate frequency synthesis technique
- Tone ringer drives piezoelectric transducer and satisfies EIA–470 requirements
- Speech network provides 2–to–4 wire conversion with adjustable sidetone utilizing an electret transmitter
- On–chip regulator insures stable operation over wide range of loop lengths
- $I^2L$ technology provides low 1.4 V operation and high static discharge immunity
- Microprocessor interface port for automatic dialing features

**Also Available**

A broad line of additional telephone components for customizing systems design.



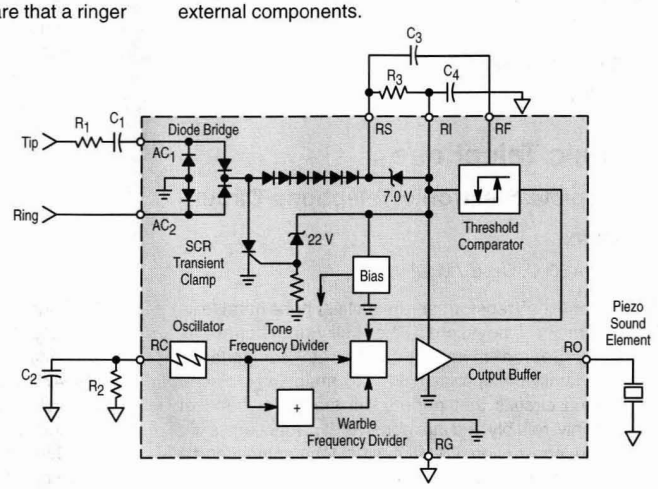
## Tone Ringers

The MC34012, MC34017, and MC34117 Tone Ringers are designed to replace the bulky bell assembly of a telephone, while providing the same function and performance under a variety of conditions. The operational requirements spelled out by the FCC and EIA–470, simply stated, are that a ringer circuit MUST function when a ringing signal is provided, and MUST NOT ring when other signals (speech, dialing, noise) are on the line. The tone ringers described below were designed to meet those requirements with a minimum of external components.

**MC34012P, D**

$T_A$ = –20° to +60°C, Case 626, 751

- Complete Telephone Bell Replacement
- On–Chip Diode Bridge and Transient Protection
- Single–Ended Output to Piezo Transducer
- Input Impedance Signature Meets Bell and EIA Standards
- Rejects Rotary Dial and Hook Switch Transients
- Adjustable Base Frequencies
- Output Frequency to Warble Ratio –
  - MC34012–1:80
  - MC34012–2:160
  - MC34012–3:40

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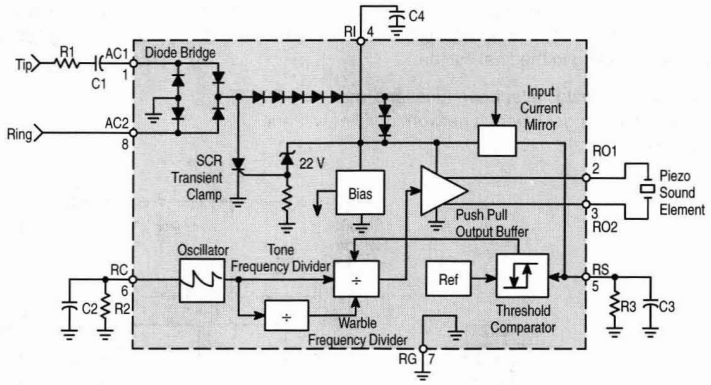
**MC34017P, D**

$T_A$ = –20° to +60°C, Case 626, 751

- Complete Telephone Bell Replacement Circuit with Minimum External Components
- On–Chip Diode Bridge and Transient Protection
- Direct Drive for Piezoelectric Transducers
- Push Pull Output Stage for Greater Output Power Capability
- Base Frequency Options
  - MC34017–1: 1.0 kHz
  - MC34017–2: 2.0 kHz
  - MC34017–3: 500 Hz
- Input Impedance Signature Meets Bell and EIA Standards
- Rejects Rotary Dial Transients

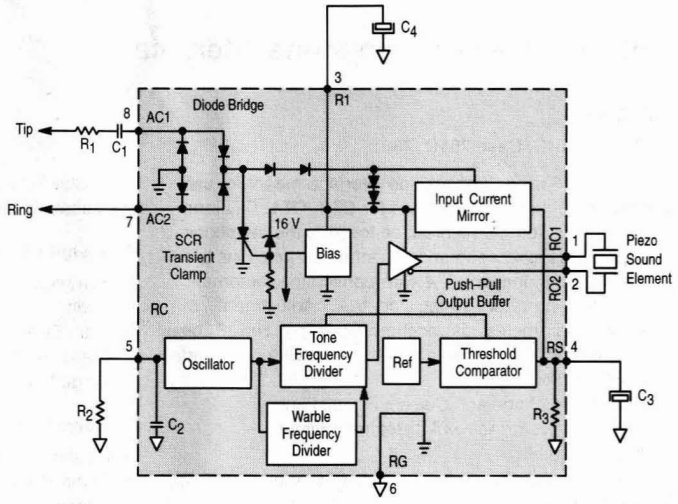


## Tone Ringers (continued)

**MC34217P, D**

$T_A$ = –20° to +60°C, Case 626, 751

- Complete Telephone Bell Replacement
- On–Chip Diode Bridge
- Internal Transient Protection
- Differential Output to Piezo Transducer for Louder Sound
- Input Impedance Signature Meets Bell and EIA Standards
- Rejects Rotary Dial and Hook Switch Transients
- Base Frequency and Warble Frequencies are Independently Adjustable
- Adjustable Base Frequency
- Reduced Number of Externals



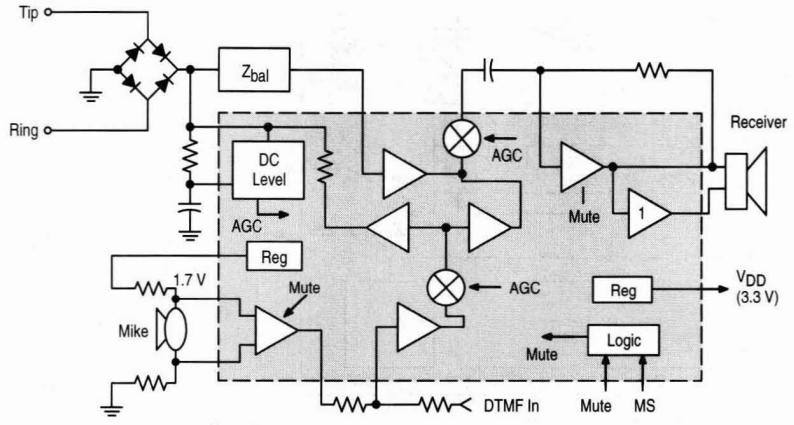

# Speech Networks

## Telephone Speech Network with Dialer Interface

**MC34114P, DW**

$T_A$ = –20° to +70°C, Case 707, 751D

- Operation Down to 1.2 V
- Adjustable Transmit, Receive, and Sidetone Gains by External Resistors
- Differential Microphone Amplifier Input Minimizes RFI
- Transmit, Receive, and Sidetone Equalization on both Voice and DTMF Signals
- Regulated 1.7 V Output for Biasing Microphone
- Regulated 3.3 V Output for Powering External Dialer
- Microphone and Receive Amplifiers Muted During Dialing
- Differential Receive Amplifier Output Eliminates Coupling Capacitor
- Operates with Receiver Impedances of 150 Ω and Higher

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# Cordless Universal Telephone Interface

**MC34016DW, P**

$T_A$ = –20° to +70°C, Case 751D, 738

The MC34016 is a telephone line interface meant for use in cordless telephone base stations for CT0, CT1, CT2 and DECT. The circuit forms the interface towards the telephone line and performs all speech and line interface functions like dc and ac line termination, 2–4 wire conversion, automatic gain control and hookswitch control. Adjustment of transmission parameters is accomplished by two 8 bit registers accessible via the integrated serial bus interface and by external components.

- DC Masks for Voltage and Current Regulation
- Supports Passive or Active AC Set Impedance Applications
- Double Wheatstone Bridge Sidetone Architecture
- Symmetrical Inputs and Outputs with Large Signal Swing Capability
- Gain Setting and Mute Function for $T_X$ and $R_X$ Amplifiers
- Very Low Noise Performance
- Serial Bus Interface SPI Compatible
- Operation from 3.0 to 5.5 V

## FEATURES

**Line Driver Architecture**

- Two DC Masks for Voltage Regulation
- Two DC Masks for Current Regulation
- Passive or Active Set Impedance Adjustment
- Double Wheatstone Bridge Architecture
- Automatic Gain Control Function

**Transmit Channel**

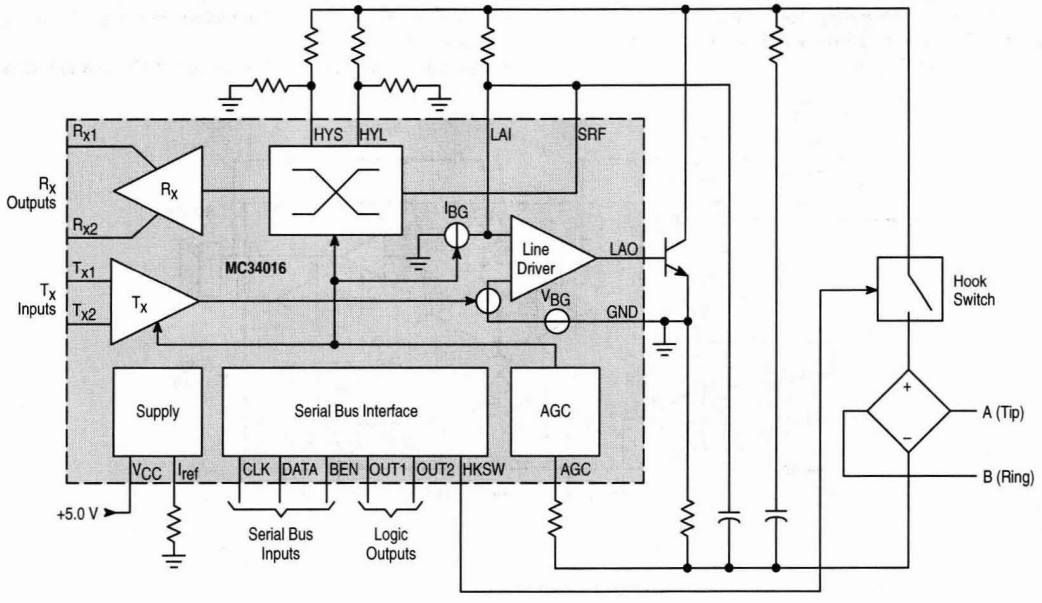
- Symmetrical Inputs Capable of Handling Large Voltage Swing
- Gain Select Option via Serial Bus Interface
- Transmit Mute Function, Programmable via Bus
- Large Voltage Swing Capability at the Telephone Line

**Receive Channel**

- Double Sidetone Architecture for Optimum Line Matching
- Symmetrical Outputs Capable of Producing High Voltage Swing
- Gain Select Option via Serial Bus Interface
- Receive Mute Function, Programmable via Serial Bus

**Serial Bus Interface**

- 3–Wire Connection to Microcontroller
- One Programmable Output Meant for Driving a Hookswitch
- Two Programmable Outputs Capable of Driving Low Ohmic Loads
- Two 8–Bit Registers for Parameter Adjustment



# Programmable Telephone Line Interface Circuit with Loudspeaker Amplifier

**MC34216DW**

$T_A$ = 0° to +70°C, Case 751F

The MC34216 is developed for use in telephone applications where besides the standard telephone functions also the group listening–in feature is required. In cooperation with a microcontroller, the circuit performs all basic telephone functions including DTMF generation and pulse–dialing. The listening–in part includes a loudspeaker amplifier, an anti–howling circuit and a strong supply. In combination with the TCA3385, the ringing is performed via the loudspeaker.

## FEATURES

### Line Driver and Supply

- DC and AC Termination of the Line
- Selectable Masks: France, U.K., Low Voltage
- Current Protection
- Adjustable Set Impedance for Resistive and Complex Termination
- Efficient Supply Point for Loudspeaker Amplifier and Peripherals

### Handset Operation

- Transmit and Receive Amplifiers
- Adjustable Sidetone Network
- Line Length AGC
- Microphone and Earpiece Mute
- Earpiece Gain Increase Switch
- Microphone Squelch Function
- Transmit Amplifier Soft Clipping

### Dialing and Ringing

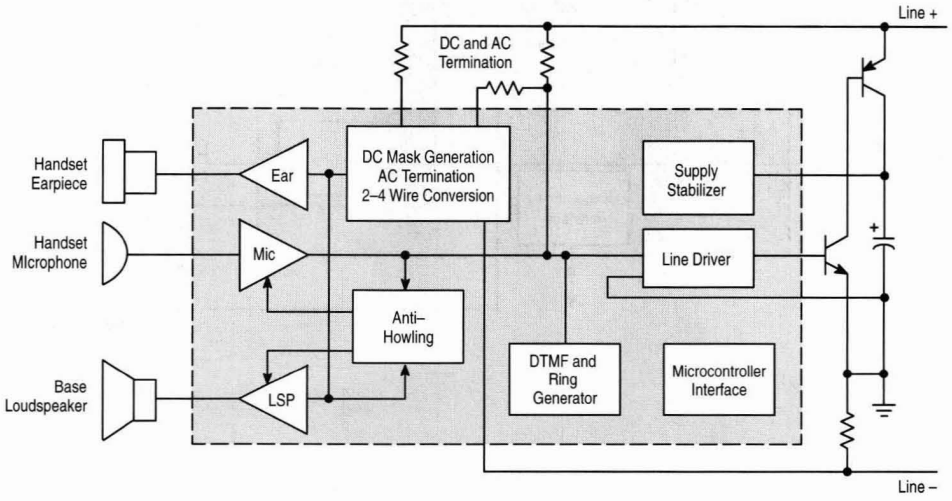
- Generates DTMF, Pilot Tones and Ring Signal
- Interrupter Driver for Pulse–Dialing
- Low Current While Pulse–Dialing
- Optimized for Ringing via Loudspeaker
- Programmable Ring Melodies
- Uses Inexpensive 500 kHz Resonator

### Loudspeaking Facility

- Integrated Loudspeaker Amplifier
- Peak–to–Peak Limiter Prevents Distortion
- Programmable Volume
- Anti–Howling Circuitry for Group Listening–In
- Interfacing for Handsfree Conversation

### Application Areas

- Corded Telephony with Group Listening–In
- Cordless Telephony Base Station with Group Listening–In
- Telephones with Answering Machines
- Fax, Intercom, Modem



# Telephone Line Interface

**TCA3388DP, FP**

$T_A$ = 0° to +70°C, Case 738, 751D

The TCA3388 is a telephone line interface circuit which performs the basic functions of a telephone set in combination with a microcontroller and a ringer. It includes dc and ac line termination, the hybrid function with 2 adjustable sidetone networks, handset connections and an efficient supply point.

## FEATURES

### Line Driver and Supply

- DC and AC Termination of the Telephone Line
- Selectable DC Mask: France, U.K., Low Voltage
- Current Protection
- Adjustable Set Impedance for Resistive and Complex Termination
- Efficient Supply Point for Peripherals
- Hook Status Detection

### Handset Operation

- Transmit and Receive Amplifiers
- Double Anti–Sidetone Network
- Line Length AGC
- Microphone and Earpiece Mute
- Transmit Amplifier Soft Clipping

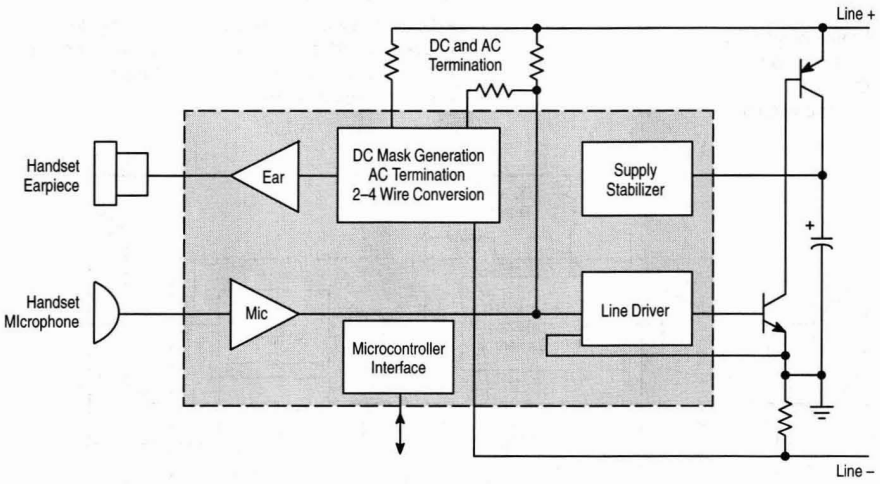
### Dialing and Ringing

- Interrupter Driver for Pulse–Dialing
- Reduced Current Consumption During Pulse–Dialing
- DTMF Interfacing
- Ringing via External Ringer

### Application Areas

- Corded Telephony
- Cordless Telephony Base Station
- Answering Machines
- Fax
- Intercom
- Modem





# Speakerphones

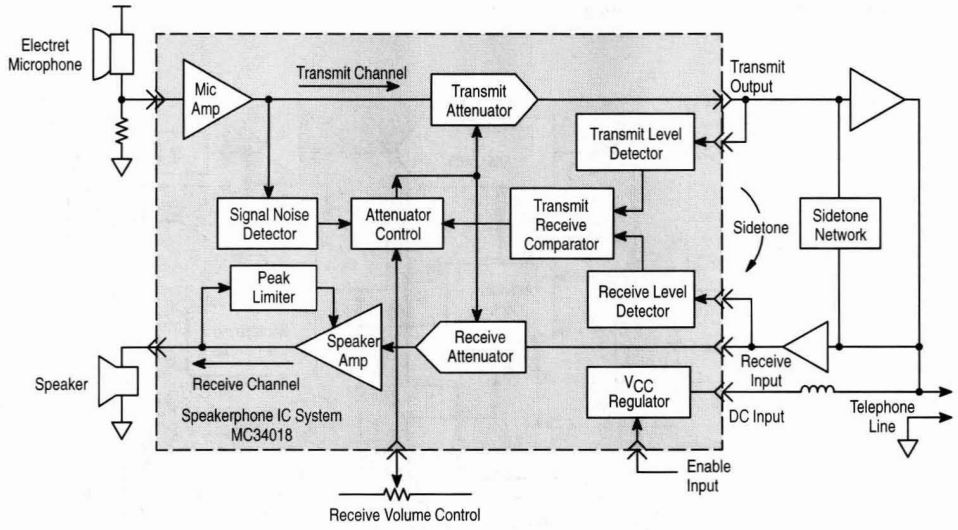
## Voice Switched Speakerphone Circuit

**MC34018P, DW**

$T_A$ = –20° to +60°C, Case 710, 751F

The MC34018 Speakerphone integrated circuit incorporates the necessary amplifiers, attenuators, and control functions to produce a high quality hands–free speakerphone system. Included are a microphone amplifier, a power audio amplifier for the speaker, transmit and receive attenuators, a monitoring system for background sound level, and an attenuation control system which responds to the relative transmit and receive levels as well as the background level. Also included are all necessary regulated voltages for both internal and external circuitry, allowing line–powered operation (no additional power supplies required). A Chip Select pin allows the chip to be powered down when not in use. A volume control function may be implemented with an external potentiometer. MC34018 applications include speakerphones for household and business uses, intercom systems, automotive telephones, and others.

- All Necessary Level Detection and Attenuation Controls for a Hands–Free Telephone in a Single Integrated Circuit
- Background Noise Level Monitoring with Long Time Constant
- Wide Operating Dynamic Range Through Signal Compression
- On–Chip Supply and Reference Voltage Regulation
- Typical 100 mW Output Power (into 25 Ω) with Peak Limiting to Minimize Distortion
- Chip Select Pin for Active/Standby Operation
- Linear Volume Control Function

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## Voice Switched Speakerphone Circuit

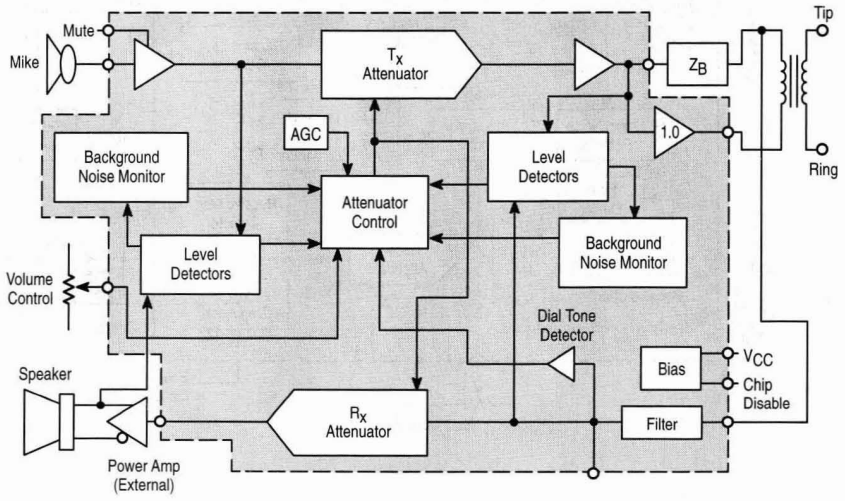
**MC34118P, DW**

$T_A$ = −20° to +60°C, Case 710, 751F

The MC34118 Voice Switched Speakerphone circuit incorporates the necessary amplifiers, attenuators, level detectors, and control algorithm to form the heart of a high quality hands–free speakerphone system. Included are a microphone amplifier with adjustable gain and mute control, Transmit and Receive attenuators which operate in a complementary manner, level detectors at input and output of both attenuators,and background noise monitors for both the transmit and receive channels. A dial tone detector prevents the dial tone from being attenuated by the Receive background noise monitor circuit. Also included are two line driver amplifiers which can be used to form a hybrid network in conjunction with an external coupling transformer. A high–pass filter can be used to filter out 60 Hz noise in the receive channel, or for other filtering functions. A Chip Disable pin permits powering down the entire circuit to conserve power on long loops where loop current is at a minimum.

The MC34118 may be operated from a power supply, or it can be powered from the telephone line, requiring typically 5.0 mA. The MC34118 can be interfaced directly to Tip and Ring (through a coupling transformer) for stand–alone operation, or it can be used in conjunction with a handset speech network and/or other features of a featurephone.

- Improved Attenuator Gain Range: 52 dB Between Transmit and Receive
- Low Voltage Operation for Line–Powered Applications (3.0 to 6.5 V)
- 4–Point Signal Sensing for Improved Sensitivity
- Background Noise Monitors for Both Transmit and Receive Paths
- Microphone Amplifier Gain Set by External Resistors – Mute Function Included
- Chip Disable for Active/Standby Operation
- On Board Filter Pinned–Out for User Defined Function
- Dial Tone Detector Inhibits Receive Idle Mode During Dial Tone Presence
- Compatible with MC34119 Speaker Amplifier



## Voice Switched Speakerphone with μProcessor Interface

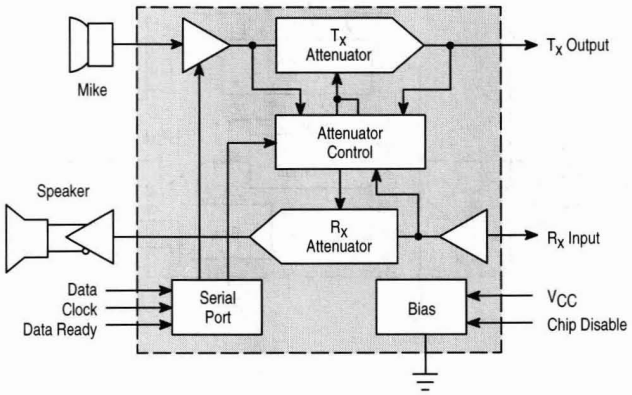
**MC33218AP, DW**

$T_A$ = –40° to +85°C, Case 724, 751E

The MC33218A, Voice Switched Speakerphone circuit incorporates the necessary amplifiers, attenuators, level detectors, and control algorithm to form the heart of a high quality hands–free speakerphone system. Included are a microphone amplifier with adjustable gain, and mute control, transmit and receive attenuators which operate in a complementary manner, and level detectors and background noise monitors for both paths. A dial tone detector prevents dial tone from being attenuated by the receive background noise monitor. A Chip Disable pin permits powering down the entire circuit to conserve power.

Also included is an 8–bit serial μprocessor port for controlling the receive volume, microphone mute, attenuator gain, and operation mode (force to transmit, force to receive, etc.). Data rate can be up to 1.0 MHz. The MC33218A can be operated from a power supply, or from the telephone line, requiring typically 3.8 mA. It can also be used in intercoms and other voice–activated applications.

- Low Voltage Operation: 2.5 to 6.0 V
- 2–Point Sensing, Background Noise Monitor in Each Path
- Chip Disable Pin for Active/Standby Operation
- Microphone Amplifier Gain Set by External Resistors – Mute Function Included
- Dial Tone Detector to Inhibit Receive Idle Mode During Dial Tone Presence
- Microprocessor port for controlling:
  - Receive Volume Level (16 Steps)
  - Attenuator Range (26 or 52 dB, Selectable)
  - Microphone Mute
  - Force to Transmit, Receive, Idle or Normal Voice Switched Operation
- Compatible with MC34119 Speaker Amplifier



## Voice Switched Speakerphone Circuit

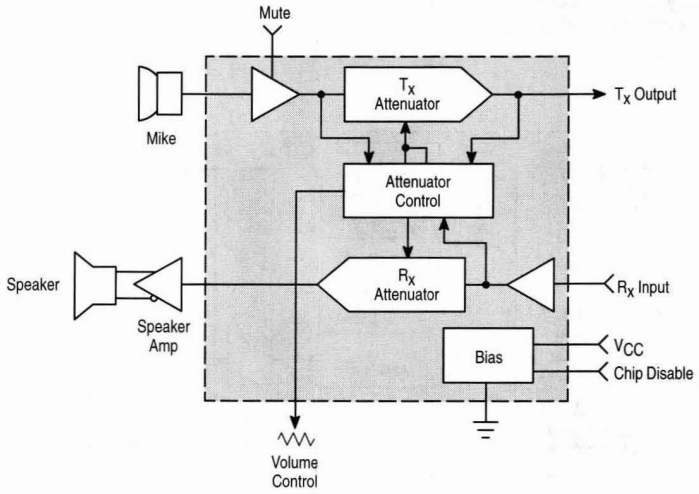
**MC33219AP, ADW**

$T_A$ = –40° to +85°C, Case 724, 751E

The MC33219A Voice Switched Speakerphone Circuit incorporates the necessary amplifiers, attenuators, level detectors, and control algorithm to form the heart of a high quality hands–free speakerphone system. Included are a microphone amplifier with adjustable gain, and mute control, transmit and receive attenuators which operate in a complementary manner, and level detectors and background noise monitors. A dial tone detector prevents dial tone from being attenuated by the receive background noise monitor. A Chip Disable pin permits powering down the entire circuit to conserve power.

The MC33219A may be operated from a power supply, or it can be powered from the telephone line requiring typically 4.0 mA. The MC33219A can be interfaced directly to Tip and Ring (through a coupling transformer for stand–alone operation, or it can be used in conjuction with a handset speech network and/or other features of a featurephone.

- Low Voltage Operation: 2.7 to 6.0 V
- 2–Point Sensing, Background Noise Monitor in Each Path
- Chip Disable Pin for Active/Standby Operation
- Microphone Amplifier Gain Set by External Resistors – Mute Function Included
- Dial Tone Detector to Inhibit Receive Idle Mode During Dial Tone Presence
- Volume Control Range: 34 dB
- Compatible with MC34119 Speaker Amplifier




8

# Telephone Line Interface and Speakerphone Circuit

**MC33215B, FB**

$T_A$ = 0° to +70°C, Case 858, 848B

The MC33215 is a combination speech network/ speakerphone developed for use in fully electronic telephone sets with a speakerphone function. The circuit performs the ac and dc line terminations, 2–4 wire conversion, line length AGC and DTMF transmission. The speakerphone part includes a half duplex controller with signal and noise monitoring, base microphone and loudspeaker amplifiers, and an efficient supply. The circuit is designed to operate at low line currents down to 4.0 mA enabling parallel operation with a classical telephone set.

## FEATURES

### Line Driver and Supply

- AC and DC Termination of Telephone Line
- Adjustable Set Impedance for Real and Complex Termination
- Efficient Supply for Speaker Amplifier and Peripherals
- Two Supplies for Handset and Base Microphones
- Separate Supply Arrangement for Handset and Speakerphone Operation

### Handset Operation

- Transmit and Receive Amplifiers
- Differential Microphone Inputs
- Sidetone Cancellation Network
- Line Length AGC
- Microphone and Earpiece Mute
- Separate Input for DTMF and Auxiliary Signals
- Parallel Operation Down to 4.0 mA of Line Current

### Speakerphone Operation

- Integrated Microphone and Loudspeaker Amplifiers
- Differential Microphone Inputs
- Loudspeaker Amplifier can be Powered and Used Separately from the Rest of the Circuit
- Integrated Switches for Smooth Switch Over from Handset to Speakerphone Mode
- Signal and Background Noise Monitoring in Both Channels
- Adjustable Switching Depth for Handsfree Operation
- Adjustable Switch Over and Idle Mode Timing
- Dial Tone Detector in the Receive Channel
- Handsfree Operation via Loudspeaker and Base Microphone

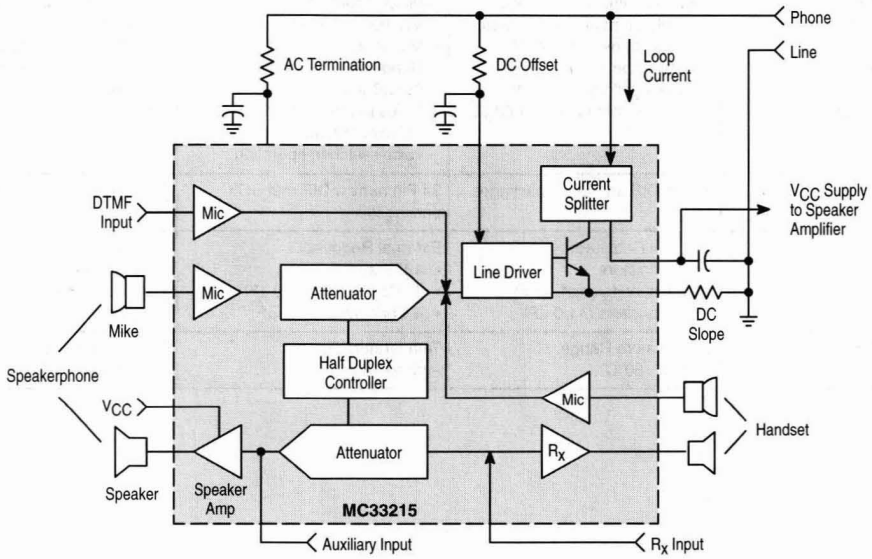


**Table 10. The Motorola Family of Speakerphone Integrated Circuits**

| MC34018 | MC34118 | MC33218A | MC33219A |
|---|---|---|---|
| Two point sensing with slow idle, background noise monitor in $T_X$ path only | Four point sensing with both fast and slow idle modes, background noise monitors in both $R_X$ and $T_X$ paths | Two point sensing with slow idle, background noise monitors in both $R_X$ and $T_X$ paths | Two point sensing with slow idle, background noise monitors in both $R_X$ and $T_X$ paths |
| No dial tone detector in receive path | Receive path has dial tone detector | Receive path has dial tone detector | Receive path has dial tone detector |
| Attenuator Characteristics:<br>• Range: 44 dB<br>• Tolerance: ±4.0 dB<br>• Gain tracking not specified<br>• White noise is constant | Attenuator Characteristics:<br>• Range: 52 dB<br>• Tolerance: ±2.0 dB<br>• Gain Tracking: <1.0 dB<br>• White noise reduces with volume | Attenuator Characteristics:<br>• Range: 52 or 26 dB (selectable)<br>• Tolerance: ±3.0 dB<br>• Gain Tracking: <1.0 dB<br>• White noise reduces with volume | Attenuator Characteristics:<br>• Range: 52 dB<br>• Tolerance: ±3.0 dB<br>• Gain Tracking: <1.0 dB<br>• White noise reduces with volume |
| External hybrid required | Hybrid amplifiers on board | External hybrid required | External hybrid required |
| Speaker amplifier is on board (34 dB, 100 mW) | External speaker amplifier required (MC34119) | External speaker amplifier required (MC34119) | External speaker amplifier required (MC34119) |
| Filtering is external | Configurable filter on board | Filtering is external | Filtering is external |
| Microphone amplifier has fixed gain and no muting | Microphone amplifier has adjustable gain and mute input | Microphone amplifier has adjustable gain, and can be muted through µP port | Microphone amplifier has adjustable gain and a mute input |
| Supply Voltage: 4.0 V to 11 V | Supply Voltage: 2.8 V to 6.5 V | Supply Voltage: 2.5 V to 6.5 V | Supply Voltage: 2.7 V to 6.5 V |
| Supply Current: 6.5 mA typ., 9.0 mA max | Supply Current: 5.5 mA typ., 8.0 mA max | Supply Current: 4.0 mA typ., 5.0 mA max | Supply Current: 3.0 mA typ., 5.0 mA max |
| Speaker amplifier reduces gain to prevent clipping | Receive gain is reduced as supply voltage falls to prevent clipping | Receive gain is reduced as supply voltage falls to prevent clipping | Receive gain is reduced as supply voltage falls to prevent clipping |
| Volume control is linear. Cannot override voice switched operation except through additional circuitry. Attenuator gain is fixed at 44 dB (slightly variable). No microphone mute. | Volume control is linear, and microphone mute has separate pin. Cannot override voice switched operation except through additional circuitry. Attenuator gain is fixed at 52 dB. | 8–bit µP serial port controls:<br>• Volume control (16 steps)<br>• Microphone mute<br>• Range selection (26 dB or 52 dB)<br>• Force to transmit, idle, receive, or normal voice switched operation | Volume control is linear, and microphone mute has separate pin. Attenuator range fixed at 52 dB. Cannot override voice switched operation except through additional circuitry. |
| 28 Pin DIP and SOIC packages | 28 Pin DIP and SOIC packages | 24 Pin narrow DIP and SOIC packages | 24 Pin narrow DIP and SOIC packages |
| External Required:<br>• 12 Resistors<br>• 11 Capacitors (≤1.0 µF)<br>• 8 Capacitors (>1.0 µF) | External Required:<br>• 14 Resistors<br>• 12 Capacitors (≤1.0 µF)<br>• 9 Capacitors (>1.0 µF) | External Required:<br>• 12 Resistors<br>• 11 Capacitors (≤1.0 µF)<br>• 4 Capacitors (>1.0 µF) | External Required:<br>• 12 Resistors<br>• 11 Capacitors (≤1.0 µF)<br>• 4 Capacitors (>1.0 µF) |
| Temperature Range:<br>–20° to +60°C | Temperature Range:<br>–20° to +60°C | Temperature Range:<br>–40° to +85°C | Temperature Range:<br>–40° to +85°C |

# Telephone Accessory Circuits

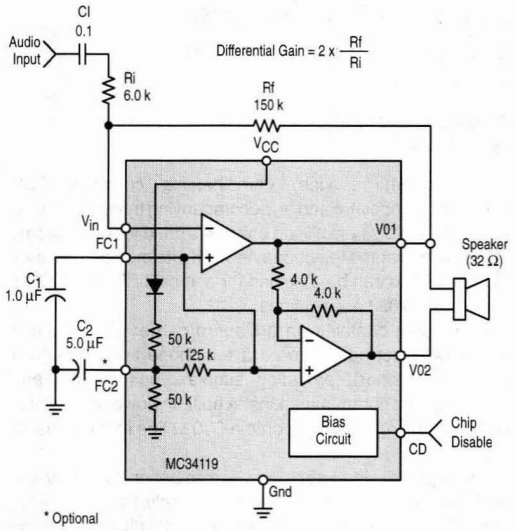
## Audio Amplifier

**MC34119P, D**

$T_A$ = 0° to +70°C, Case 626, 751

A low power audio amplifier circuit intended (primarily) for telephone applications, such as speakerphones. Provides differential speaker outputs to maximize output swing at low supply voltages (2.0 V min.). Coupling capacitors to the speaker, and snubbers, are not required. Overall gain is externally adjustable from 0 to 46 dB. A Chip Disable pin permits powering–down to mute the audio signal and reduce power consumption.

- Drives a Wide Range of Speaker Loads (16 to 100 Ω)
- Output Power Exceeds 250 mW with 32 Ω Speaker
- Low Distortion (THD = 0.4% Typical)
- Wide Operating Supply Voltage (2.0 V to 16 V) – Allows Telephone Line Powered Applications.
- Low Quiescent Supply Current (2.5 mA Typical)
- Low Power–Down Quiescent Current (60 μA Typical)




## Current Mode Switching Regulator

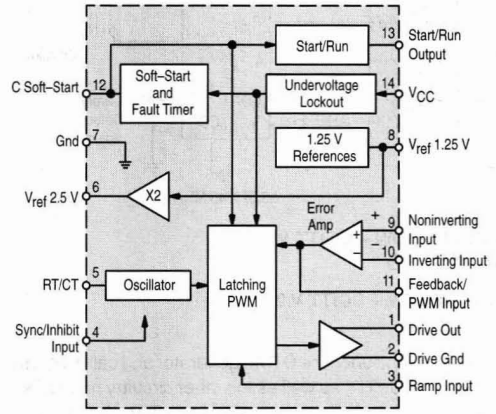
**MC34129P, D**

$T_A$ = 0° to +70°C, Case 646, 751A

High performance current mode switching regulator for low–power digital telephones. Unique internal fault timer provides automatic restart for overload recovery. A start/run comparator is included to implement bootstrapped operation of $V_{CC}$.

Although primarily intended for digital telephone systems, these devices can be used cost effectively in many other applications. On–chip functions and features include:

- Current Mode Operation to 300 kHz
- Automatic Feed Forward Compensation
- Latching PWM for Cycle–By–Cycle Current Limiting
- Latched–Off or Continuous Retry after Fault Timeout
- Soft–Start with Maximum Peak Switch Current Clamp
- Internally Trimmed 2% Bandgap Reference
- Input Undervoltage Lockout




8

## 300 Baud FSK Modems

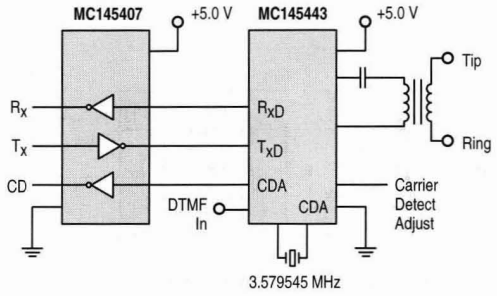
**MC145442P, DW Modem – CCITT V.21**
Case 738, 751D

**MC145443P, DW Modem – Bell 103**
Case 738, 751D

This powerful modem combines a complete FSK modulator/demodulator and an accompanying transmit/receive filter system on a single silicon chip. Designed for bidirectional transmission over the telephone network, the modem operates at 300 baud and can be obtained for compatibility with CCITT V.21 and Bell 103 specifications.

The modem contains an on–board carrier–detect circuit that allows direct operation on a telephone line (through a simple transformer), providing simplex, half–duplex, and full–duplex data communications. A built–in power amplifier is capable of driving –9.0 dBm onto a 600 Ω line in the transmit mode.

CMOS processing keeps power dissipation to a very low 45 mW, with a power–down dissipation of only 1.0 mW . . . from a single 5.0 V power supply. Available in a 20 pin dual–in–line P suffix, and a wide body surface mount DW suffix.




**MC145444H, DW – CCITT V.21**
Case 804, 751D

**MC145446AFW – CCITT V.21**
Case 751M

This device includes the DTMF generator and call progress tone detector (CPTD) as well as the other circuitry needed for full–duplex, half–duplex, or simplex 300 baud data communication over a pair of telephone lines. It is intended for use with telemeter system or remote control system applications.

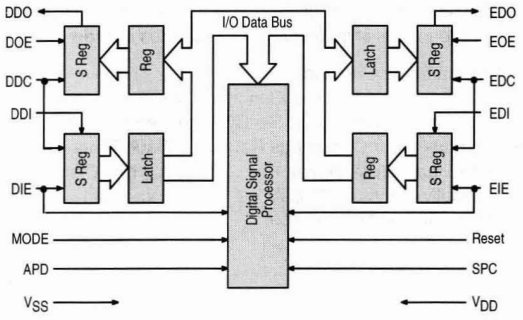
The differential line driver is capable of driving 0 dBm into a 600 Ω load. The transmit attenuator is programmable in 1.0 dB steps.

## ADPCM Transcoder

**MC145532DW, L**
Case 751G, 620

The MC145532 Adaptive Differential Pulse Code Modulation (ADPCM) Transcoder provides a low cost, full–duplex, single–channel transcoder to (from) a 64 kbps PCM channel from (to) either a 16 kbps, 24 kbps, 32 kbps, or 64 kbps channel.

- Complies with CCITT Recommendation G.721 (1988)
- Complies with the American National Standard (T1.301–1987)
- Full–Duplex, Single–Channel Operation
- Mu–Law or A–Law Coding is Pin Selectable
- Synchronous or Asynchronous Operation
- Easily Interfaces with any Member of Motorola's PCM Codec–Filter Mono–Circuit Family or Other Industry Standard Codecs
- Serial PCM and ADPCM Data Transfer Rate from 64 kbps to 5.12 Mbps
- Power Down Capability for Low Cost Consumption
- The Reset State is Automatically Initiated when the Reset Pin is Released.
- Simple Time Slot Assignment Timing for Transcoder Applications
- Single 5.0 V Power Supply
- Evaluation Kit MC145536 EVK Supports the MC145532 as well as the MC14LC5480 PCM Codec–Filter. (See PBX Architecture Pages for More Information.)



## Calling Line Identification (CLID) Receiver with Ring Detector

**MC14LC5447P, DW**

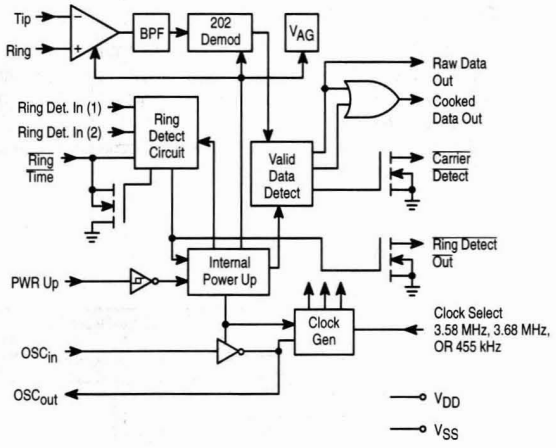
Case 648, 751G

The MC14LC5447 is designed to demodulate Bell 202 1200 baud FSK asynchronous data. Its primary application is in products that will be used to receive and display the calling number, or the message waiting indicator sent to subscribers from participating central office facilities of the public switched telephone network. The device also contains a carrier detect circuit and telephone ring detector which may be used to power up the device.

Applications include adjunct boxes, answering machines, feature phones, fax machines, and computer interface products.

Replaces MC145447P, DW.

- Ring Detector On–Chip
- Ring Detect Output for MCU Interrupt
- Power–Down Mode Less Than 1.0 μA
- Single Supply: 3.5 V to 6.0 V
- Pin Selectable Clock Frequencies: 3.68 MHz, 3.58 MHz, or 455 kHz
- Two–Stage Power–Up for Power Management Control

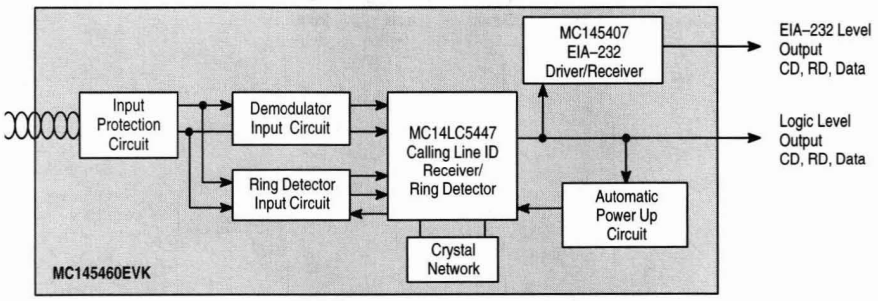



## Calling Line ID Receiver Evaluation Kit

**MC145460EVK**

The MC145460EVK is a low cost evaluation platform for the MC14LC5447. The MC145460EVK facilitates development and testing of products that support the Bellcore customer premises equipment (CPE) data interface, which enables services such as Calling Number Delivery (CND). The MC14LC5447 can be easily incorporated into any telephone, FAX, PBX, key system, answering machine, CND adjunct box or other telephone equipment with the help of the MC145460EVK development kit.

- Easy Clip–On Access to Key MC14LC5447 Signals
- Generous Prototype Area
- Configurable for MC14LC5447 Automatic or External Power Up Control
- EIA–232 and Logic Level Ports for Connection to any PC or MCU Development Platform
- Carrier Detect, Ring Detect and Data Status LEDs
- Optional Tip and Ring Input Protection Network
- MC145460EVK User Guide, MC14LC5447 Data Sheet, and Additional MC14LC5447 Sample Included

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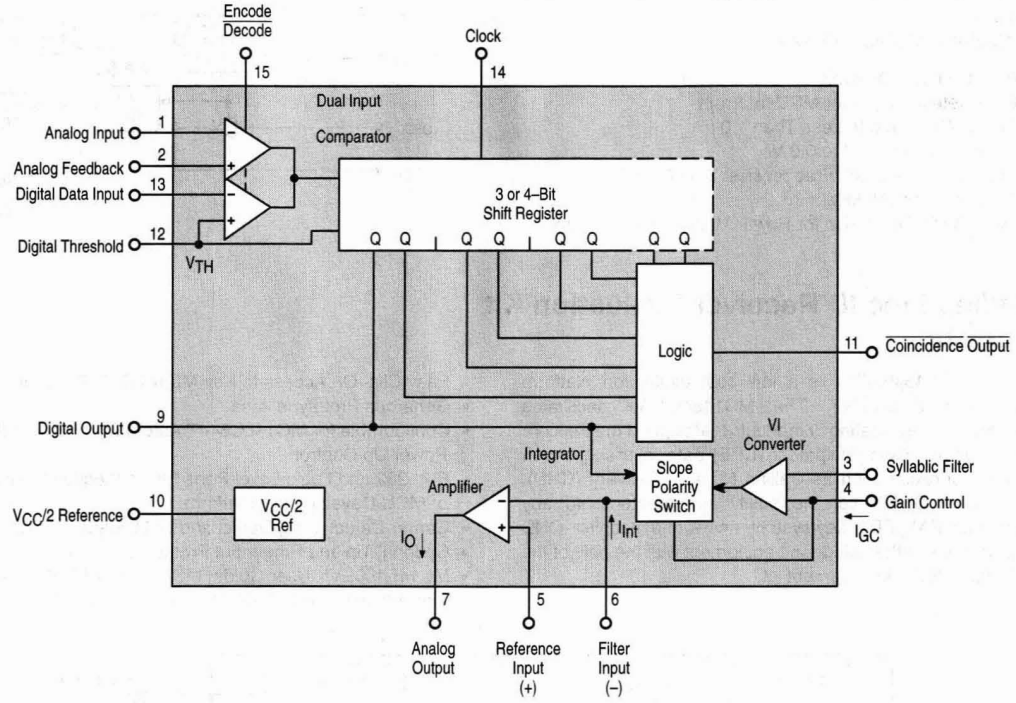
## Continuously Variable Slope Delta (CVSD) Modulator/Demodulator

**MC34115P, DW**
$T_A$ = 0° to +70°C, Case 648, 751G

**MC3418P, DW**
$T_A$ = 0° to +70°C, Case 648, 751G

Provides the A/D–D/A function of voice communications by digital transmission. Designed for speech synthesis and commercial telephone applications. A single IC provides both encoding and decoding.

- Encode and Decode Functions on the Same Chip with a Digital Input
- CMOS Compatible Digital Output
- Digital Input Threshold Selectable ($V_{CC}$/2 reference provided on Chip)
- MC34115 Has a 3–Bit Algorithm (General Communications)
- MC3418 Has a 4–Bit Algorithm (Commercial Telephone)



## Table 11. Summary of Bipolar Telecommunication Circuits

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| **Subscriber Loop Interface Circuits (SLICs)** | | | |
| Central Office, Remote Terminals, PBX Applications | All gains externally programmable, most BORSHT functions, current limit adjustable to 50 mA, 58 dB Longitudinal Balance, –21.6 V to –42 V. | P/738, FN/776 | MC33121 |
| Central Office, Remote Terminals, PBX Applications | All gains externally programmable, most BORSHT functions, current limit adjustable to 50 mA, 58 dB Longitudinal Balance, –42 V to –58 V. | P/738, FN/776 | MC33120 |
| **Complete Telephone Circuit** | | | |
| POTS Circuit + MPU Dialing | Speech network, tone ringer, dc loop current interface, DTMF dialer with serial port control. | P/711, FN/777 | MC34010 |
| **Tone Ringers** | | | |
| Adjustable Tone Ringer | Single–ended output, meets FCC requirements, adjustable REN, different warble rates. | P/626, D/751 | MC34012–1, 2, 3 |
| Adjustable Tone Ringer | Differential output, meets FCC requirements, adjustable REN, different warble rates. | P/626, D/751 | MC34017–1, 2, 3 |
| Adjustable Tone Ringer | Differential output, meets FCC requirements, adjustable REN, single warble rates. | P/626, D/751 | MC34217 |
| Ring Signal Converter | Switching regulator to convert ringing voltage to regulated dc output. Provides ring detect output. | DP/626, FP/751 | TCA3385 |
| **Speech Networks** | | | |
| Speech Network + Speakerphone | Line powered IC provides handset and speakerphone modes, dialer interface, ac/dc terminations, and AGC. Efficient supply design provides 90% of loop current to the speaker amplifier. Speaker amplifier may be used independently. Handset operation to 4.0 mA. | B/858, FB/848B | MC33215 |
| Basic Phone Line Interface | Loop current interface, speech network, line length compensation, speech/dialing modes, Bell System compliant. | P/707, DW/751D | MC34014 |
| Cordless Universal Telephone Interface | For cordless telephone base for CT0, CT1, CT2 and DECT. European dc masks, double wheatstone bridge sidetone circuit. SPI port for masks, AGC hookswitch, mute and gain settings. Requires 5.0 V and μP. | P/738, DW/751D | MC34016 |
| Basic Phone Line Interface | Loop current interface, speech network, line length compensation, speech/dialing modes, Bell System and foreign countries. | P/707, DW/751D | MC34114 |
| Programmable Telephone Line Interface Circuit with Loudspeaker Amplifier | Group listening–in, DTMF and tones generator, ring generator, country programmable, SPI interface. | DW/751F | MC34216 |
| European Speech Network, Programmable Speaker Amplifier | Line powered. European dc masks, DTMF and pilot tone generator, listening–in mode with anti–howling. 2–wire bus control masks, DTMF tones, speaker gain, pulse dialing, mute, AGC. Requires MCU. | DW/751 | MC34216A |
| European Speech Network | Loop current interface, speech network, line length compensation, speech/dialing modes, programmable masks for French, U.K., low voltage and PABX systems. | DP/738, FP/751 | TCA3388 |

## Telephone Accessory Circuits (continued)

### Summary of Bipolar Telecommunications Circuits (continued)

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| **Speakerphone Circuits** | | | |
| Speech Network + Speakerphone | Line powered IC provides handset and speakerphone modes, dialer interface, ac/dc terminations, and AGC. Efficient supply design provides 90% of loop current to the speaker amplifier. Speaker amplifier may be used independently. Handset operation to 4.0 mA. | B/858, FB/848B | MC33215 |
| Complete Speaker Phone with Speaker Amplifier | All level detection (2 pt.), attenuators, and switching controls, mike and speaker amp. | P/710, DW/751F | MC34018 |
| Complete Speaker Phone with Hybrid, Filter | All level detection (4 pt.), attenuators, and switching controls, mike amp with mute, hybrid, and filter. | P/710, DW/751F | MC34118 |
| Complete Speaker Phone with MPU Interface | All level detection, attenuators, and switching controls, mike amp, MPU interface for: volume control, mode selection, mike mute. | P/724, DW/751E | MC33218A |
| Basic Low Cost Speakerphone | All level detection, attenuators and switching controls, Mike amplifier with Mute, low voltage operation. | P/724, DW/751E | MC33219A |
| **Audio Amplifiers** | | | |
| 1 Watt Audio Amp | 1.0 W output power into 16 Ω, 35 V maximum. | D/751 | MC13060 |
| Low Voltage Audio Amp | 400 mW, 8.0 to 100 Ω, 2.0 to 16 V, differential outputs, chip–disable input pin. | P/626, D/751 | MC34119 |
| **Companders** | | | |
| Basic Compander | 2.1 V to 7.0 V, no precision externals, 80 dB range, –40° to +85°C, independent compressor and expander. | P/646, D/751A | MC33110 |
| Compander with Features | 3.0 V to 7.0 V, no precision externals, 80 dB range, –40° to +85°C, independent compressor and expander, pass through and mute functions, two op amps. | P/648, D/751B | MC33111 |
| **Switching Regulator** | | | |
| Current Mode Regulator | For phone line power applications, soft–start, current limiting, 2% accuracy. | P/646, D/751A | MC34129 |
| **Voice Encoder/Decoders** | | | |
| Continuously Variable Slope Modulator/Demodulator (CVSD) | Telephone quality voice encoding/decoding, variable clock rate, 3–bit coding, for secure communications, voice storage/retrieval, answering machines, 0° to 70°C. | P/738, DW/751G | MC34115 |
| | Same as above except 4–bit coding. | P/738, DW751G | MC3418 |

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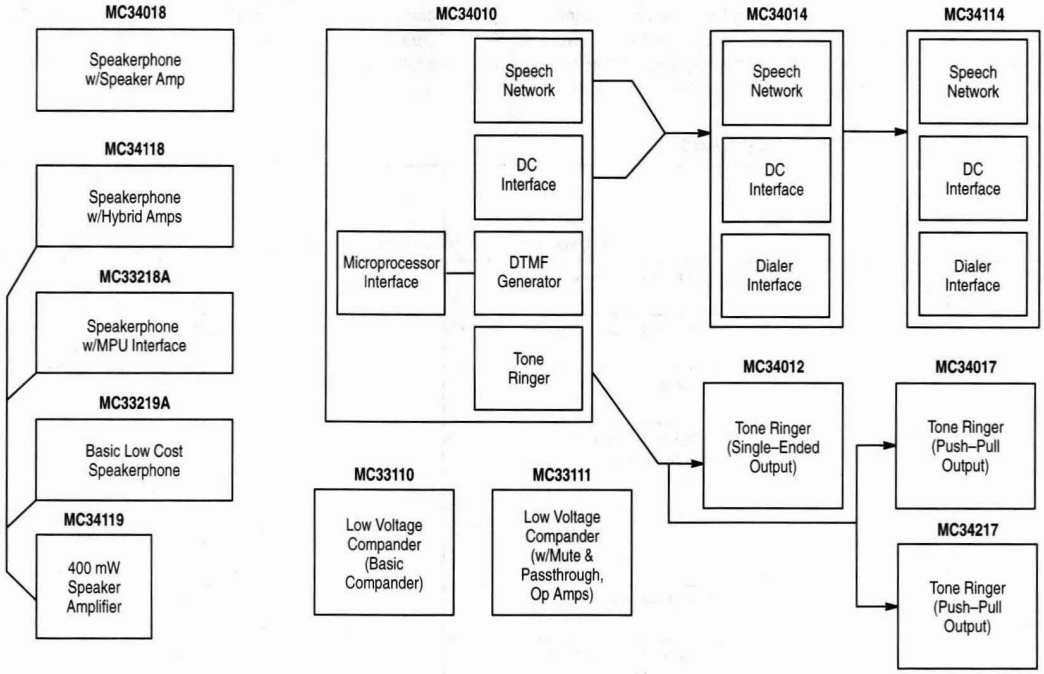
**Figure 3. The Motorola Family of Handset Telecom Integrated Circuits**




8

# Phase–Locked Loop Components

Motorola offers a choice of phase–locked loop components ranging from complete functional frequency synthesizers for dedicated applications to a wide selection of general purpose PLL circuit elements. Technologies include CMOS for lowest power consumption and bipolar for high speed operation. Typical applications include TV, CATV, radios, scanners, cordless telephones plus home and personal computers.

**Table 12. PLL Frequency Synthesizers**

| Frequency (MHz) | Supply Voltage (V) | Nominal Supply Current (mA) | Phase Detector | Standby | Interface | Device | Suffix/ Case |
|---|---|---|---|---|---|---|---|
| 4.0 @ 5.0 V | 4.5 to 12 | 6.0 @ 5.0 V | Single–ended 3–state | No | Parallel | MC145106 | P/707, DW/751D |
| 15 @ 5.0 V | 3.0 to 9.0 | – | Two single–ended 3–state | | Serial | MC145149* | P/738, DW/751D |
| | | 7.5 @ 5.0 V | Analog | | | MC145159–1 | P/738, DW/751D |
| 20 @ 5.0 V | 3.0 to 9.0 | 7.5 @ 5.0 V | Single–ended 3–state, double–ended | | 4–Bit | MC145145–2 | P/707, DW/751D |
| | | | | | | MC145146–2 | P/738, DW/751D |
| | | | | | Parallel | MC145151–2 | P/710, DW/751F |
| | | | Double–ended | | | MC145152–2 | P/710, DW/751F |
| | | | Single–ended 3–state, double–ended | | Serial | MC145155–2 | P/707, DW/751D |
| | | | | | | MC145156–2 | P/707, DW/751D |
| | | | | | | MC145157–2 | P/648, DW/751G |
| | | | | | | MC145158–2 | P/648, DW/751G |
| 60 @ 3.0 V | 2.5 to 5.5 | 3.0 @ 3.0 V | Two single–ended 3–state | Yes | | MC145162* | P/648, DW/751G |
| 60 @ 2.0 V | 1.8 to 3.6 | 1.5 @ 1.8 V | | | | MC145165* | P/648, D/751B |
| 60 @ 3.0 V | 2.5 to 5.5 | 3.0 @ 3.0 V | | | Parallel | MC145166* | P/648, DW/751G |
| | | | | | Serial | MC145167* | P/648, DW/751G |
| | | | | | Parallel | MC145168* | |
| | | | | | Serial | MC145169* | |
| 85 @ 3.0 V | 2.5 to 5.5 | 3.0 @ 3.0 V | | | | MC145162–1* | P/648, DW/751G |
| 40/130 @ 5.0 V | 4.5 to 5.5 | 9.0 @ 5.0 V | Single–ended 3–state, Current source/sink | | | MC145173 | DW/751E |
| 100 @ 3.0 V<br>185 @ 5.0 V | 2.5 to 5.5 | 2.0 @ 3.0 V<br>6.0 @ 5.0 V | | No | | MC145170–1 | P/648, D/751B |

* Dual PLL

## Phase–Locked Loop Components (continued)

### PLL Frequency Synthesizers (continued)

| Frequency (MHz) | Supply Voltage (V) | Nominal Supply Current (mA) | Phase Detector | Standby | Interface | Device | Suffix/ Case |
|---|---|---|---|---|---|---|---|
| 1100 @ 5.0 V | 4.5 to 5.5 | 7.0 @ 5.0 V | Current source/sink, double–ended | Yes | Serial | MC145190 | F/751J, DT/948D |
| | | | | | | MC145191 | F/751J, DT/948D |
| 1100 @ 3.0 V | 2.7 to 5.0 | 6.0 @ 2.7 V | | | | MC145192 | F/751J, DT/948D |
| 1100 @ 3.0 V | 2.7 to 5.5 | 12 | Two current source/sink, double–ended | | | MC145220* | F/803C, DT/948D |
| 2000 @ 5.0 V | 4.5 to 5.5 | 12 @ 5.0 V | Current source/sink, double–ended | | | MC145200 | F/751J, DT/948D |
| 2000 @ 5.0 V | 4.5 to 5.5 | 12 @ 5.0 V | | | | MC145201 | F/751J, DT/948D |
| 2000 @ 3.0 V | 2.7 to 5.5 | 4.0 @ 3.0 V | | | | MC145202 | F/751J, DT/948D |
| 1100 @ 3.0 V | 2.7 to 5.5 | 12 | Two current source/sink, double–ended | | | MC145220* | F/803C, DT/948D |

* Dual PLL

### Table 13. Phase–Locked Loop Functions

| Device | Function | Pins | DIP | SM |
|---|---|---|---|---|
| MC4016 | Programmable Modulo–N Counters (N=0–9) | 16 | P,L | |
| MC4018 | Programmable Modulo–N Counters (N=0–9) | 16 | P,L | |
| MC4024 | Dual Voltage–Controlled Multivibrator | 14 | P,L | |
| MC4044 | Phase–Frequency Detector | 14 | P,L | D |
| MC4316 | Programmable Modulo–N Counters (N=0–9) | 16 | P,L | |
| MC4324 | Dual Voltage–Controlled Multivibrator | 14 | P,L | |
| MC4344 | Phase–Frequency Detector | 14 | P,L | |
| MC12002 | Analog Mixer | 14 | P,L | |
| MC12009 | 480 MHz ÷5/6 Dual Modulus Prescaler | 16 | P,L | |
| MC12011 | 550 MHz ÷8/9 Dual Modulus Prescaler | 16 | P,L | |
| MC12013 | 550 MHz ÷10/11 Dual Modulus Prescaler | 16 | P,L | |
| MC12014 | Counter Control Logic | 16 | P,L | |
| MC12015 | 225 MHz ÷32/33 Dual Modulus Prescaler | 8 | P,L | D |
| MC12016 | 225 MHz ÷40/41 Dual Modulus Prescaler | 8 | P,L | D |
| MC12017 | 225 MHz ÷64/65 Dual Modulus Prescaler | 8 | P,L | D |
| MC12018 | 520 MHz ÷128/129 Dual Modulus Prescaler | 8 | P,L | D |
| MC12019 | 225 MHz ÷20/21 Dual Modulus Prescaler | 8 | P,L | D |
| MC12022A | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12022B | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |

**Phase–Locked Loop Functions (continued)**

| Device | Function | Pins | DIP | SM |
|---|---|---|---|---|
| MC12022LVA | 1.1 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12022LVB | 1.1 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12022SLA | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12022SLB | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12022TSA | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12022TSB | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12022TVA | 1.1 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12022TVB | 1.1 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12023 | 225 MHz ÷64 Prescaler | 8 | P | D |
| MC12025 | 520 MHz ÷64/65 Dual Modulus Prescaler | 8 | P | D |
| MC12026A | 1.1 GHz ÷8/9, ÷16/17 Dual Modulus Prescaler | 8 | P | D |
| MC12026B | 1.1 GHz ÷8/9, ÷16/17 Dual Modulus Prescaler | 8 | P | D |
| MC12028A | 1.1 GHz ÷32/33, ÷64/65 Dual Modulus Prescaler | 8 | P | D |
| MC12028B | 1.1 GHz ÷32/33, ÷64/65 Dual Modulus Prescaler | 8 | P | D |
| MC12031A | 2.0 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12031B | 2.0 GHz ÷64/65, ÷128/129 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12032A | 2.0 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12032B | 2.0 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler | 8 | P | D |
| MC12033A | 2.0 GHz ÷32/33, ÷64/65 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12033B | 2.0 GHz ÷32/33, ÷64/65 Low Voltage Dual Modulus Prescaler | 8 | P | D |
| MC12034A | 2.0 GHz ÷32/33, ÷64/65 Dual Modulus Prescaler | 8 | P | D |
| MC12034B | 2.0 GHz ÷32/33, ÷64/65 Dual Modulus Prescaler | 8 | P | D |
| MC12036A | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler with Stand–By Mode | 8 | P | D |
| MC12036B | 1.1 GHz ÷64/65, ÷128/129 Dual Modulus Prescaler with Stand–By Mode | 8 | P | D |
| MC12040 | Phase–Frequency Detector | 14 | P,L | FN |
| MC12061 | Crystal Oscillator | 16 | P,L | |
| MC12073 | 1.1 GHz ÷64 Prescaler | 8 | P | D |
| MC12074 | 1.1 GHz ÷256 Prescaler | 8 | P | D |
| MC12076 | 1.3 GHz ÷256 Prescaler | 8 | P | D |
| MC12078 | 1.3 GHz ÷256 Prescaler | 8 | P | D |
| MC12079 | 2.8 GHz ÷64/128/256 Prescaler | 8 | P | D |
| MC12080 | 1.1 GHz ÷10/20/40/80 Prescaler | 8 | P | D |
| MC12083 | 1.1 GHz ÷2 Low Power Prescaler with Stand–By Mode | 8 | P | D |
| MC12089 | 2.8 GHz ÷64/128/256 Low Power Prescaler | 8 | P | D |
| MC12090 | 750 MHz ÷2 UHF Prescaler | 16 | P,L | |
| MC12100 | 200 MHz Voltage Controlled Multivibrator | 20 | P | FN |
| MC12101 | 130 MHz Voltage Controlled Multivibrator | 20 | P | FN |
| MCH12140 | Phase–Frequency Detector | 8 | | D |
| MCK12140 | Phase–Frequency Detector | 8 | | D |
| MC12148 | Low Power Voltage Controlled Oscillator | 8 | | D,SD |

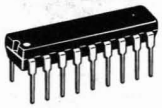
# Communications Circuits Package Overview

CASE 620
L SUFFIX

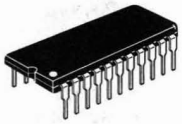
CASE 626
P SUFFIX

CASE 646
P SUFFIX

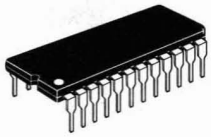
CASE 648
P SUFFIX



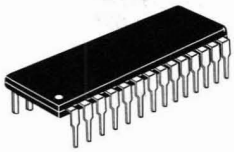
CASE 707
P SUFFIX



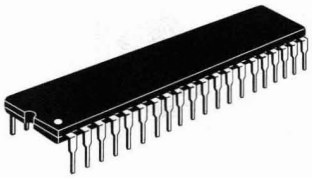
CASE 708
P SUFFIX



CASE 709
P SUFFIX



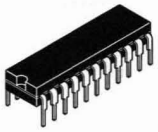
CASE 710
P SUFFIX



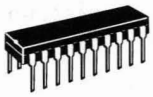
CASE 711
P SUFFIX

CASE 724
P SUFFIX

CASE 726
L SUFFIX



CASE 736B
PB SUFFIX



CASE 738
DP, P SUFFIX

CASE 751
D, D1 SUFFIX

CASE 751A
D SUFFIX

CASE 751B
D SUFFIX

CASE 751D
DW, FP SUFFIX

CASE 751E
DW SUFFIX

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## Communications Circuits Package Overview (continued)

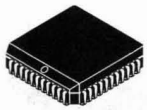
CASE 751F
DW SUFFIX

CASE 751G
DW SUFFIX

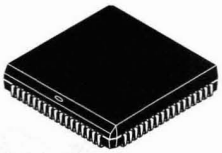
CASE 751J
F SUFFIX

CASE 751M
FW SUFFIX

CASE 776
FN SUFFIX

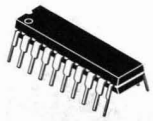


CASE 777
FN SUFFIX



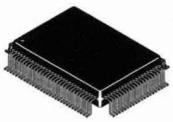
CASE 779
FN SUFFIX

CASE 803C
F SUFFIX

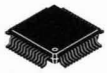


CASE 804
H SUFFIX

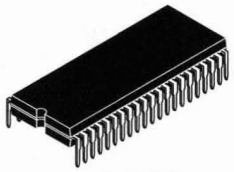
CASE 837A
DW SUFFIX



CASE 842D
PB SUFFIX



CASE 848B
FB SUFFIX



CASE 858
B SUFFIX

CASE 873
FB, FTB, FU SUFFIX

CASE 932
FTA SUFFIX

CASE 940C
SD SUFFIX

CASE 948D
DT SUFFIX

CASE 948F
DTB SUFFIX

CASE 976
FTB SUFFIX

CASE 977
FTA SUFFIX

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# Device Listing and Related Literature

## RF Communications


| Device | Function | Page |
|---|---|---|
| MC1496 | Balanced Modulators/Demodulators | 8–45 |
| MC2833 | Low Power FM Transmitter System | 8–55 |
| MC3335 | Low Power Narrowband FM Receiver | 8–62 |
| MC3356 | Wideband FSK Receiver | 8–66 |
| MC3357 | Low Power Narrowband FM IF | 8–72 |
| MC3359 | Low Power Narrowband FM IF | 8–76 |
| MC3362 | Low Power Narrowband FM Receiver | 8–82 |
| MC3363 | Low Power Dual Conversion FM Receiver | 8–89 |
| MC3371, MC3372 | Low Power Narrowband FM IF | 8–97 |
| MC3374 | Low Voltage FM Narrowband Receiver | 8–114 |
| MC13055 | Wideband FSK Receiver | 8–121 |
| MC13135, MC13136 | FM Communications Receivers | 8–214 |
| MC13141 | Low Power DC – 1.8 GHz LNA and Mixer | 8–226 |
| MC13142 | Low Power DC – 1.8 GHz LNA, Mixer and VCO | 8–235 |
| MC13143 | Ultra Low Power DC – 2.4 GHz Linear Mixer | 8–245 |
| MC13144 | VHF – 2.0 GHz Low Noise Amplifier with Programmable Bus | 8–252 |
| MC13150 | Narrowband FM Coilless Detector IF Subsystem | 8–258 |
| MC13155 | Wideband FM IF | 8–275 |
| MC13156 | Wideband FM IF System | 8–290 |
| MC13158 | Wideband FM IF Subsystem | 8–308 |
| MC13159 | Wideband FM IF Amplifier | 8–330 |
| MC13173 | Infrared Integrated Transceiver IC | 8–336 |
| MC13175, MC13176 | UHF FM/AM Transmitter | 8–353 |


## Telecommunications


| Device | Function | Page |
|---|---|---|
| MC3418 | Continuously Variable Slope Delta Modulator/Demodulator | * |
| MC13109 | Universal Cordless Telephone Subsystem IC | 8–128 |
| MC13110 | Universal Cordless Telephone Subsystem IC with Scrambler | 8–154 |
| MC13111 | Universal Cordless Telephone Subsystem IC | 8–185 |
| MC33110 | Low Voltage Compander | * |
| MC33111 | Low Voltage Compander with Mute and Feedthrough | * |
| MC33120 | Subscriber Loop Interface Circuit | * |
| MC33121 | Low Voltage Subscriber Loop Interface Circuit | * |
| MC33215 | Telephone Line Interface and Speakerphone Circuit | ** |
| MC33218A | Voice Switched Speakerphone with Microprocessor Interface | * |
| MC33219A | Voice Switched Speakerphone | * |
| MC34010 | Electronic Telephone Circuit | * |
| MC34012 | Telephone Tone Ringer | * |
| MC34014 | Telephone Speech Network with Dialer Interface | * |
| MC34016 | Cordless Universal Telephone Interface | * |
| MC34017 | Telephone Tone Ringer | * |
| MC34018 | Voice Switched Speakerphone Circuit | * |
| MC34114 | Telephone Speech Network with Dialer Interface | * |
| MC34115 | Continuously Variable Slope Delta Modulator/Demodulator | * |
| MC34117 | Telephone Tone Ringer | * |
| MC34118 | Voice Switched Speakerphone Circuit | * |


**See Communications Device Data* (DL136)

** Call Sales Office.

## Telecommunications (continued)

| | | |
|---|---|---|
| **MC34119** | Low Power Audio Amplifier | See Chapter 9 |
| **MC34129, MC33129** | High Performance Current Mode Controllers | See Chapter 3 |
| **MC34216A** | Programmable Telephone Line Interface Circuit with Loudspeaker Amplifier | * |
| **TCA3385** | Telephone Ring Signal Converter | * |
| **TCA3388** | Telephone Speech Network | * |

**See Communications Device Data* (DL136)

## RELATED APPLICATION NOTES

| App Note | Title | Related Device |
|---|---|---|
| AN933 | A Variety of Uses for the MC34012/MC34017 Tone Ringers | **MC34012, MC34017** |
| AN937 | A Telephone Ringer which Complies with FCC and EIA Impedance Standards | **MC34012, MC34017** |
| AN957 | Interfacing the Speakerphone to the MC34010/11/13 Speech Networks | **MC34010** |
| AN958 | Transmit Gain Adjustments for the MC34014 Speech Network | **MC34014** |
| AN959 | A Speakerphone with Receive Idle Mode | **MC34018** |
| AN960 | Equalization of DTMF Signals Using the MC34014 | **MC34014** |
| AN976 | A New High Performance Current Mode Controller Teams Up with Current Sensing Power MOSFETs | **MC34129** |
| AN980 | Low Power FM Dual Conversion Receivers | **MC3362, MC3363** |
| AN1002 | A Handsfree Featurephone Design Using the MC34114 Speech Network and the MC34018 Speakerphone ICs | **MC34018 MC34114** |
| AN1003 | A Featurephone Design, with Tone Ringer and Dialer, Using the MC34118 Speakerphone IC | **MC34118, MC34017, MC145412, MC34119** |
| AN1004 | A Handsfree Featurephone Design Using the MC34114 Speech Network and the MC34118 Speakerphone ICs | **MC34114, MC34118, MC34119, MC3417, MC145412** |
| AN1006 | Linearize the Volume Control of the MC34118 Speakerphone | **MC34118** |
| AN1077 | Adding Digital Volume Control to Speakerphone Circuits | **MC34018, MC34118** |
| AN1081 | Minimize the "Pop" in the MC34119 Power Audio Amplifiers | **MC34119** |
| AN1510 | A Mode Indicator for the MC34118 Speakerphone Circuit | **MC34118** |
| AN1544 | Design of Continuously Variable Slope Delta Modulation Communications Systems | **MC3418, MC34115** |
| AN1575 | Worldwide Cordless Telephone Frequencies | **MC13109, MC13110, MC13111** |

## OTHER RELATED LITERATURE

| | |
|---|---|
| DL136 | Communications Device Data |
| SG98 | Linear Telecom Cross Reference |

MOTOROLA

# MC1496, B

## Balanced Modulators/ Demodulators

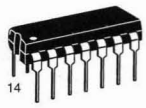
**BALANCED MODULATORS/DEMODULATORS**

**SEMICONDUCTOR TECHNICAL DATA**

These devices were designed for use where the output voltage is a product of an input voltage (signal) and a switching function (carrier). Typical applications include suppressed carrier and amplitude modulation, synchronous detection, FM detection, phase detection, and chopper applications. See Motorola Application Note AN531 for additional design information.

- Excellent Carrier Suppression –65 dB typ @ 0.5 MHz
  –50 dB typ @ 10 MHz
- Adjustable Gain and Signal Handling
- Balanced Inputs and Outputs
- High Common Mode Rejection –85 dB typical

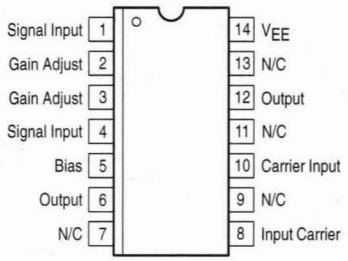
This device contains 8 active transistors.




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**P SUFFIX**
PLASTIC PACKAGE
CASE 646

**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1496D | $T_A$ = 0°C to +70°C | SO–14 |
| MC1496P | | Plastic DIP |
| MC1496BP | $T_A$ = –40°C to +125°C | Plastic DIP |

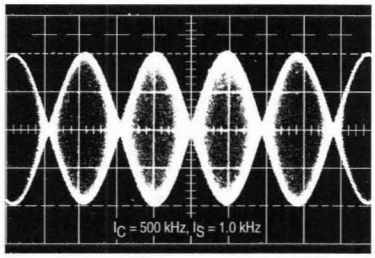



**Figure 1. Suppressed Carrier Output Waveform**

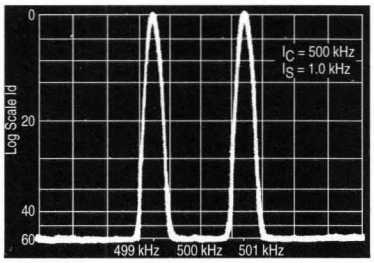



**Figure 2. Suppressed Carrier Spectrum**

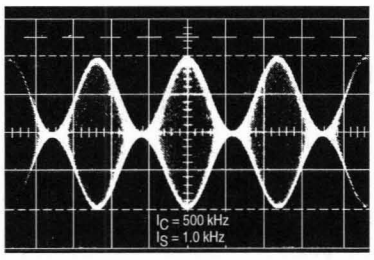
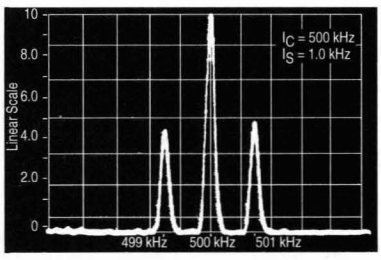



**Figure 3. Amplitude Modulation Output Waveform**

**Figure 4. Amplitude–Modulation Spectrum**




8

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Applied Voltage (V6 – V8, V10 – V1, V12 – V8, V12 – V10, V8 – V4, V8 – V1, V10 – V4, V6 – V10, V2 – V5, V3 – V5) | ΔV | 30 | Vdc |
| Differential Input Signal | V8 – V10<br>V4 – V1 | +5.0<br>±(5+I5$R_e$) | Vdc |
| Maximum Bias Current | $I_5$ | 10 | mA |
| Thermal Resistance, Junction–to–Air Plastic Dual In–Line Package | $R_{\theta JA}$ | 100 | °C/W |
| Operating Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 12 Vdc, $V_{EE}$ = –8.0 Vdc, I5 = 1.0 mAdc, $R_L$ = 3.9 kΩ, $R_e$ = 1.0 kΩ, $T_A$ = $T_{low}$ to $T_{high}$, all input and output characteristics are single–ended, unless otherwise noted.)

| Characteristic | Fig. | Note | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Carrier Feedthrough | 5 | 1 | $V_{CFT}$ | | | | μVrms |
| $V_C$ = 60 mVrms sine wave and $f_C$ = 1.0 kHz | | | | – | 40 | – | |
| offset adjusted to zero $f_C$ = 10 MHz | | | | – | 140 | – | |
| $V_C$ = 300 mVpp square wave: | | | | | | | mVrms |
| offset adjusted to zero $f_C$ = 1.0 kHz | | | | – | 0.04 | 0.4 | |
| offset not adjusted $f_C$ = 1.0 kHz | | | | – | 20 | 200 | |
| Carrier Suppression | 5 | 2 | $V_{CS}$ | | | | dB |
| $f_S$ = 10 kHz, 300 mVrms | | | | | | | |
| $f_C$ = 500 kHz, 60 mVrms sine wave | | | | 40 | 65 | – | |
| $f_C$ = 10 MHz, 60 mVrms sine wave | | | | – | 50 | – | k |
| Transadmittance Bandwidth (Magnitude) ($R_L$ = 50 Ω) | 8 | 8 | $BW_{3dB}$ | | | | MHz |
| Carrier Input Port, $V_C$ = 60 mVrms sine wave | | | | – | 300 | – | |
| $f_S$ = 1.0 kHz, 300 mVrms sine wave | | | | | | | |
| Signal Input Port, $V_S$ = 300 mVrms sine wave | | | | – | 80 | – | |
| $\|V_C\|$ = 0.5 Vdc | | | | | | | |
| Signal Gain ($V_S$ = 100 mVrms, f = 1.0 kHz; $\|V_C\|$= 0.5 Vdc) | 10 | 3 | $A_{VS}$ | 2.5 | 3.5 | – | V/V |
| Single–Ended Input Impedance, Signal Port, f = 5.0 MHz | 6 | – | | | | | |
| Parallel Input Resistance | | | $r_{ip}$ | – | 200 | – | kΩ |
| Parallel Input Capacitance | | | $c_{ip}$ | – | 2.0 | – | pF |
| Single–Ended Output Impedance, f = 10 MHz | 6 | – | | | | | |
| Parallel Output Resistance | | | $r_{op}$ | – | 40 | – | kΩ |
| Parallel Output Capacitance | | | $c_{oo}$ | – | 5.0 | – | pF |
| Input Bias Current | 7 | – | | | | | μA |
| $I_{bS} = \frac{I1 + I4}{2}$; $I_{bC} = \frac{I8 + I10}{2}$ | | | $I_{bS}$<br>$I_{bC}$ | –<br>– | 12<br>12 | 30<br>30 | |
| Input Offset Current | 7 | – | | | | | μA |
| $I_{ioS}$ = I1–I4; $I_{ioC}$ = I8–I10 | | | $\|I_{ioS}\|$<br>$\|I_{ioC}\|$ | –<br>– | 0.7<br>0.7 | 7.0<br>7.0 | |
| Average Temperature Coefficient of Input Offset Current ($T_A$ = –55°C to +125°C) | 7 | – | $\|TC_{Iio}\|$ | – | 2.0 | – | nA/°C |
| Output Offset Current (I6–I9) | 7 | – | $\|I_{oo}\|$ | – | 14 | 80 | μA |
| Average Temperature Coefficient of Output Offset Current ($T_A$ = –55°C to +125°C) | 7 | – | $\|TC_{Ioo}\|$ | – | 90 | – | nA/°C |
| Common–Mode Input Swing, Signal Port, $f_S$ = 1.0 kHz | 9 | 4 | CMV | – | 5.0 | – | Vpp |
| Common–Mode Gain, Signal Port, $f_S$ = 1.0 kHz, $\|V_C\|$= 0.5 Vdc | 9 | – | ACM | – | –85 | – | dB |
| Common–Mode Quiescent Output Voltage (Pin 6 or Pin 9) | 10 | – | $V_{out}$ | – | 8.0 | – | Vpp |
| Differential Output Voltage Swing Capability | 10 | – | $V_{out}$ | – | 8.0 | – | Vpp |
| Power Supply Current I6 +I12 | 7 | 6 | $I_{CC}$ | – | 2.0 | 4.0 | mAdc |
| I14 | | | $I_{EE}$ | – | 3.0 | 5.0 | |
| DC Power Dissipation | 7 | 5 | $P_D$ | – | 33 | – | mW |

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## GENERAL OPERATING INFORMATION

### Carrier Feedthrough

Carrier feedthrough is defined as the output voltage at carrier frequency with only the carrier applied (signal voltage = 0).

Carrier null is achieved by balancing the currents in the differential amplifier by means of a bias trim potentiometer (R1 of Figure 5).

### Carrier Suppression

Carrier suppression is defined as the ratio of each sideband output to carrier output for the carrier and signal voltage levels specified.

Carrier suppression is very dependent on carrier input level, as shown in Figure 22. A low value of the carrier does not fully switch the upper switching devices, and results in lower signal gain, hence lower carrier suppression. A higher than optimum carrier level results in unnecessary device and circuit carrier feedthrough, which again degenerates the suppression figure. The MC1496 has been characterized with a 60 mVrms sinewave carrier input signal. This level provides optimum carrier suppression at carrier frequencies in the vicinity of 500 kHz, and is generally recommended for balanced modulator applications.

Carrier feedthrough is independent of signal level, $V_S$. Thus carrier suppression can be maximized by operating with large signal levels. However, a linear operating mode must be maintained in the signal–input transistor pair – or harmonics of the modulating signal will be generated and appear in the device output as spurious sidebands of the suppressed carrier. This requirement places an upper limit on input–signal amplitude (see Figure 20). Note also that an optimum carrier level is recommended in Figure 22 for good carrier suppression and minimum spurious sideband generation.

At higher frequencies circuit layout is very important in order to minimize carrier feedthrough. Shielding may be necessary in order to prevent capacitive coupling between the carrier input leads and the output leads.

### Signal Gain and Maximum Input Level

Signal gain (single–ended) at low frequencies is defined as the voltage gain,

$$A_{VS} = \frac{V_o}{V_S} = \frac{R_L}{R_e + 2r_e} \text{ where } r_e = \frac{26 \text{ mV}}{I5(\text{mA})}$$

A constant dc potential is applied to the carrier input terminals to fully switch two of the upper transistors "on" and two transistors "off" ($V_C$ = 0.5 Vdc). This in effect forms a cascode differential amplifier.

Linear operation requires that the signal input be below a critical value determined by $R_E$ and the bias current I5.

$$V_S \leq I5\ R_E \text{ (Volts peak)}$$

Note that in the test circuit of Figure 10, $V_S$ corresponds to a maximum value of 1.0 V peak.

### Common Mode Swing

The common–mode swing is the voltage which may be applied to both bases of the signal differential amplifier, without saturating the current sources or without saturating the differential amplifier itself by swinging it into the upper switching devices. This swing is variable depending on the particular circuit and biasing conditions chosen.

### Power Dissipation

Power dissipation, $P_D$, within the integrated circuit package should be calculated as the summation of the voltage–current products at each port, i.e. assuming V12 = V6, I5 = I6 = I12 and ignoring base current, $P_D$ = 2 I5 (V6 – V14) + I5) V5 – V14 where subscripts refer to pin numbers.

### Design Equations

The following is a partial list of design equations needed to operate the circuit with other supply voltages and input conditions.

A. Operating Current

The internal bias currents are set by the conditions at Pin 5. Assume:

$$I5 = I6 = I12,$$
$$I_B << I_C \text{ for all transistors}$$

then :

$$R5 = \frac{V - -\phi}{I5} - 500\ \Omega$$

where: R5 is the resistor between Pin 5 and ground
$\phi$ = 0.75 at $T_A$ = +25°C

The MC1496 has been characterized for the condition $I_5$ = 1.0 mA and is the generally recommended value.

B. Common–Mode Quiescent Output Voltage

$$V6 = V12 = V+ - I5\ R_L$$

### Biasing

The MC1496 requires three dc bias voltage levels which must be set externally. Guidelines for setting up these three levels include maintaining at least 2.0 V collector–base bias on all transistors while not exceeding the voltages given in the absolute maximum rating table;

$$30 \text{ Vdc} \geq [(V6, V12) - (V8, V10)] \geq 2 \text{ Vdc}$$
$$30 \text{ Vdc} \geq [(V8, V10) - (V1, V4)] \geq 2.7 \text{ Vdc}$$
$$30 \text{ Vdc} \geq [(V1, V4) - (V5)] \geq 2.7 \text{ Vdc}$$

The foregoing conditions are based on the following approximations:

$$V6 = V12,\ V8 = V10,\ V1 = V4$$

Bias currents flowing into Pins 1, 4, 8 and 10 are transistor base currents and can normally be neglected if external bias dividers are designed to carry 1.0 mA or more.

### Transadmittance Bandwidth

Carrier transadmittance bandwidth is the 3.0 dB bandwidth of the device forward transadmittance as defined by:

$$\gamma 21C = \frac{i_o \text{ (each sideband)}}{v_s \text{ (signal)}} \Bigg| V_o = 0$$

Signal transadmittance bandwidth is the 3.0 dB bandwidth of the device forward transadmittance as defined by:

$$\gamma 21S = \frac{i_o \text{ (signal)}}{v_s \text{ (signal)}} \Bigg| V_C = 0.5 \text{ Vdc},\ V_o = 0$$

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### Coupling and Bypass Capacitors

Capacitors C1 and C2 (Figure 5) should be selected for a reactance of less than 5.0 Ω at the carrier frequency.

### Output Signal

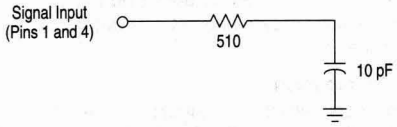
The output signal is taken from Pins 6 and 12 either balanced or single–ended. Figure 11 shows the output levels of each of the two output sidebands resulting from variations in both the carrier and modulating signal inputs with a single–ended output connection.

### Negative Supply

$V_{EE}$ should be dc only. The insertion of an RF choke in series with $V_{EE}$ can enhance the stability of the internal current sources.

### Signal Port Stability

Under certain values of driving source impedance, oscillation may occur. In this event, an RC suppression network should be connected directly to each input using short leads. This will reduce the Q of the source–tuned circuits that cause the oscillation.




An alternate method for low–frequency applications is to insert a 1.0 kΩ resistor in series with the input (Pins 1, 4). In this case input current drift may cause serious degradation of carrier suppression.

## TEST CIRCUITS

**Figure 5. Carrier Rejection and Suppression**

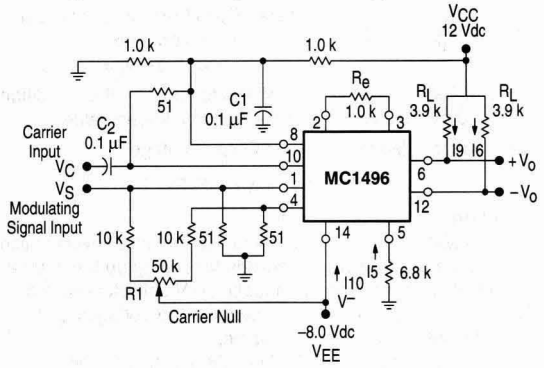
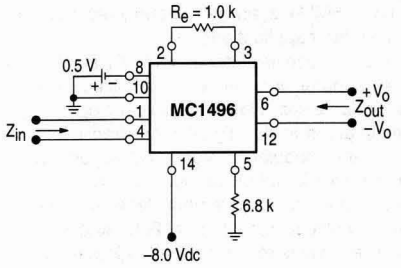



**Figure 6. Input–Output Impedance**




**NOTE:** Shielding of input and output leads may be needed to properly perform these tests.

**Figure 7. Bias and Offset Currents**

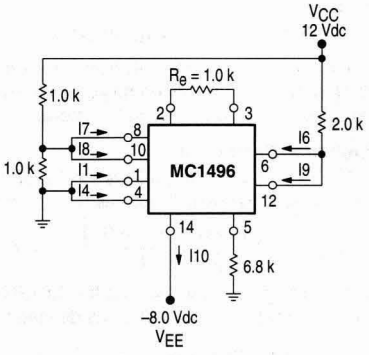



**Figure 8. Transconductance Bandwidth**

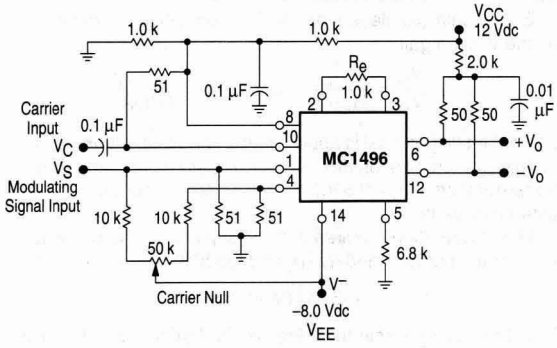


**Figure 9. Common Mode Gain**

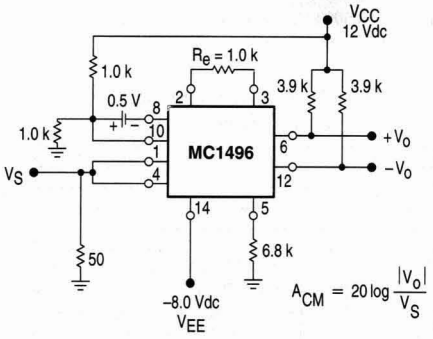
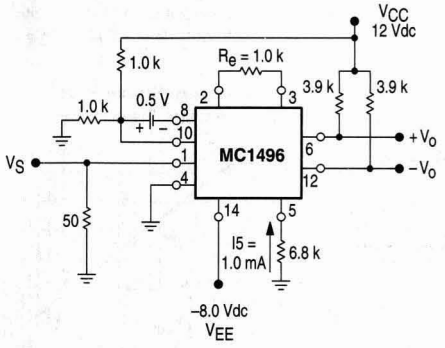



**Figure 10. Signal Gain and Output Swing**




## TYPICAL CHARACTERISTICS

Typical characteristics were obtained with circuit shown in Figure 5, $f_C$ = 500 kHz (sine wave), $V_C$ = 60 mVrms, $f_S$ = 1.0 kHz, $V_S$ = 300 mVrms, $T_A$ = 25°C, unless otherwise noted.

**Figure 11. Sideband Output versus Carrier Levels**

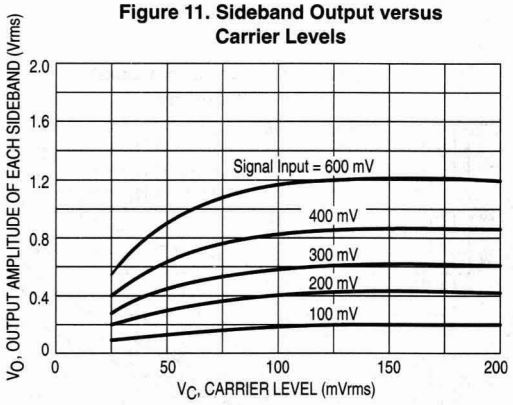



**Figure 12. Signal–Port Parallel–Equivalent Input Resistance versus Frequency**

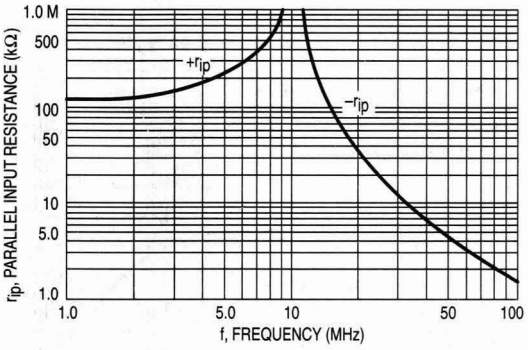



**Figure 13. Signal–Port Parallel–Equivalent Input Capacitance versus Frequency**

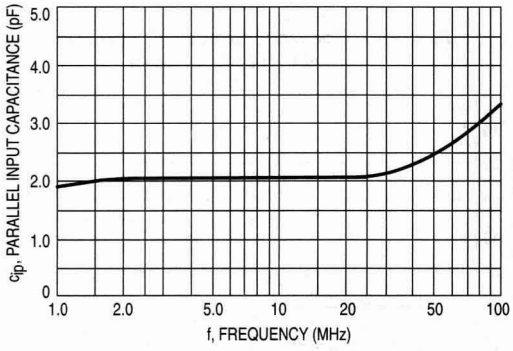
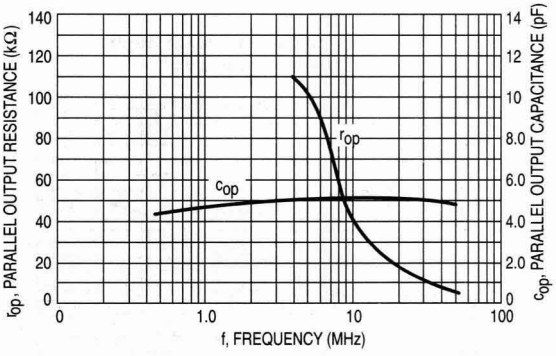



**Figure 14. Single–Ended Output Impedance versus Frequency**

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## TYPICAL CHARACTERISTICS (continued)

Typical characteristics were obtained with circuit shown in Figure 5, $f_C$ = 500 kHz (sine wave), $V_C$ = 60 mVrms, $f_S$ = 1.0 kHz, $V_S$ = 300 mVrms, $T_A$ = 25°C, unless otherwise noted.

**Figure 15. Sideband and Signal Port Transadmittances versus Frequency**

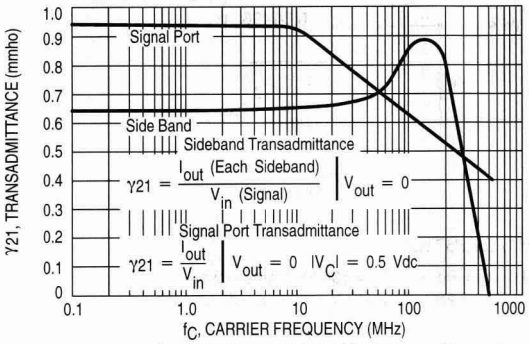

Signal Port
Side Band
Sideband Transadmittance
Y21 = Iout (Each Sideband) / Vin (Signal) | Vout = 0
Signal Port Transadmittance
Y21 = Iout / Vin | Vout = 0 IVCI = 0.5 Vdc
Y21, TRANSADMITTANCE (mmho)
fC, CARRIER FREQUENCY (MHz)

**Figure 16. Carrier Suppression versus Temperature**

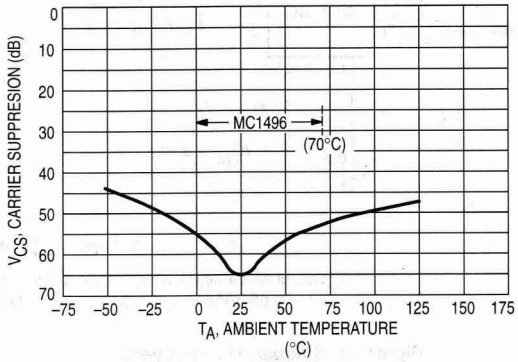



**Figure 17. Signal–Port Frequency Response**

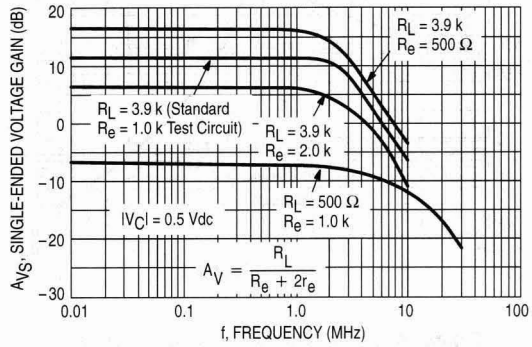

RL = 3.9 k
Re = 500 Ω
RL = 3.9 k (Standard
Re = 1.0 k Test Circuit)
RL = 3.9 k
Re = 2.0 k
IVCI = 0.5 Vdc
RL = 500 Ω
Re = 1.0 k
AV = RL / (Re + 2re)
AVS, SINGLE-ENDED VOLTAGE GAIN (dB)
f, FREQUENCY (MHz)

**Figure 18. Carrier Suppression versus Frequency**

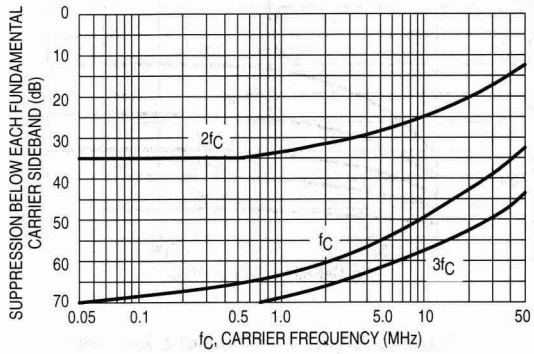



**Figure 19. Carrier Feedthrough versus Frequency**

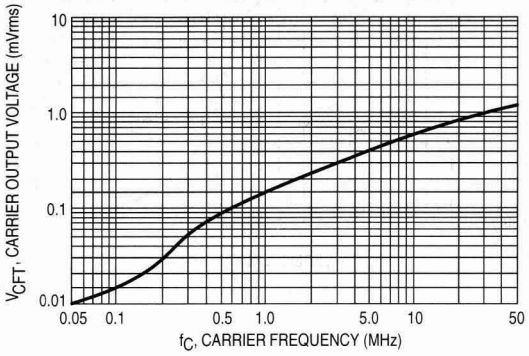



**Figure 20. Sideband Harmonic Suppression versus Input Signal Level**

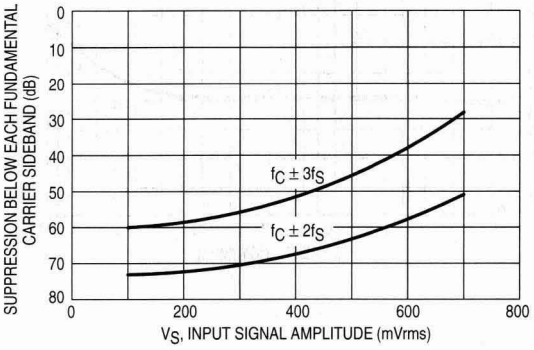


**Figure 21. Suppression of Carrier Harmonic Sidebands versus Carrier Frequency**

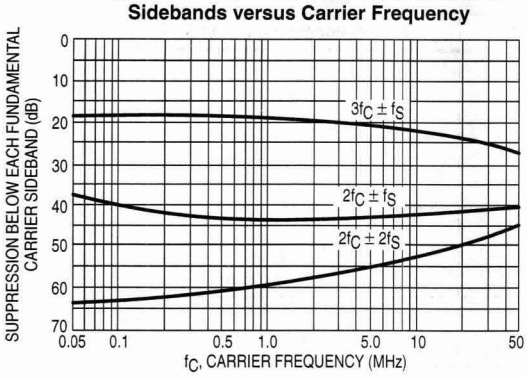
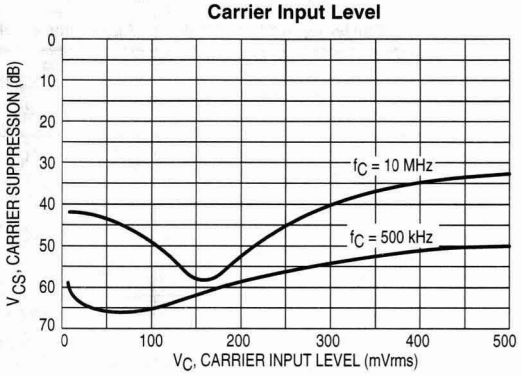



**Figure 22. Carrier Suppression versus Carrier Input Level**




## OPERATIONS INFORMATION

The MC1496, a monolithic balanced modulator circuit, is shown in Figure 23.

This circuit consists of an upper quad differential amplifier driven by a standard differential amplifier with dual current sources. The output collectors are cross–coupled so that full–wave balanced multiplication of the two input voltages occurs. That is, the output signal is a constant times the product of the two input signals.

Mathematical analysis of linear ac signal multiplication indicates that the output spectrum will consist of only the sum and difference of the two input frequencies. Thus, the device may be used as a balanced modulator, doubly balanced mixer, product detector, frequency doubler, and other applications requiring these particular output signal characteristics.

The lower differential amplifier has its emitters connected to the package pins so that an external emitter resistance may be used. Also, external load resistors are employed at the device output.

### Signal Levels

The upper quad differential amplifier may be operated either in a linear or a saturated mode. The lower differential amplifier is operated in a linear mode for most applications.

For low–level operation at both input ports, the output signal will contain sum and difference frequency components and have an amplitude which is a function of the product of the input signal amplitudes.

For high–level operation at the carrier input port and linear operation at the modulating signal port, the output signal will contain sum and difference frequency components of the modulating signal frequency and the fundamental and odd harmonics of the carrier frequency. The output amplitude will be a constant times the modulating signal amplitude. Any amplitude variations in the carrier signal will not appear in the output.

The linear signal handling capabilities of a differential amplifier are well defined. With no emitter degeneration, the maximum input voltage for linear operation is approximately 25 mV peak. Since the upper differential amplifier has its emitters internally connected, this voltage applies to the carrier input port for all conditions.

Since the lower differential amplifier has provisions for an external emitter resistance, its linear signal handling range may be adjusted by the user. The maximum input voltage for linear operation may be approximated from the following expression:

$$V = (I5)\,(R_E) \text{ volts peak.}$$

This expression may be used to compute the minimum value of $R_E$ for a given input voltage amplitude.

**Figure 23. Circuit Schematic**

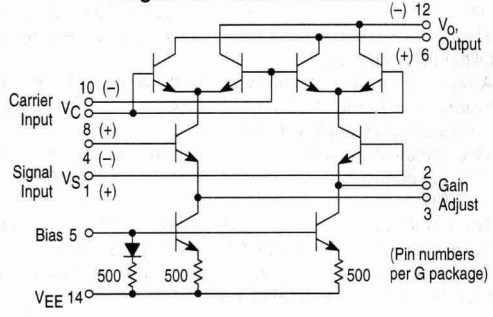



**Figure 24. Typical Modulator Circuit**

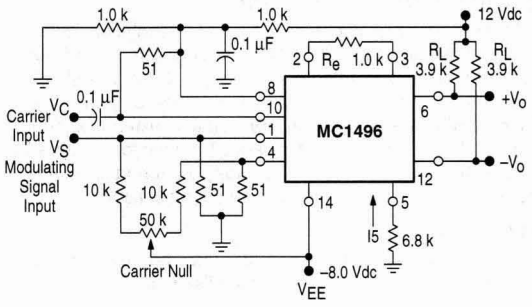



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**Figure 25. Voltage Gain and Output Frequencies**

| Carrier Input Signal ($V_C$) | Approximate Voltage Gain | Output Signal Frequency(s) |
|---|---|---|
| Low–level dc | $\frac{R_L V_C}{2(R_E + 2r_e)\left(\frac{KT}{q}\right)}$ | $f_M$ |
| High–level dc | $\frac{R_L}{R_E + 2r_e}$ | $f_M$ |
| Low–level ac | $\frac{R_L V_C(rms)}{2\sqrt{2}\left(\frac{KT}{q}\right)(R_E + 2r_e)}$ | $f_C \pm f_M$ |
| High–level ac | $\frac{0.637\ R_L}{R_E + 2r_e}$ | $f_C \pm f_M, 3f_C \pm f_M, 5f_C \pm f_M, \ldots$ |

**NOTES:** 1. Low–level Modulating Signal, $V_M$, assumed in all cases. $V_C$ is Carrier Input Voltage.
2. When the output signal contains multiple frequencies, the gain expression given is for the output amplitude of each of the two desired outputs, $f_C + f_M$ and $f_C - f_M$.
3. All gain expressions are for a single–ended output. For a differential output connection, multiply each expression by two.
4. $R_L$ = Load resistance.
5. $R_E$ = Emitter resistance between Pins 2 and 3.
6. $r_e$ = Transistor dynamic emitter resistance, at 25°C;
$$re \approx \frac{26\ mV}{I_5\ (mA)}$$
7. K = Boltzmann's Constant, T = temperature in degrees Kelvin, q = the charge on an electron.
$$\frac{KT}{q} \approx 26\ mV \text{ at room temperature}$$

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The gain from the modulating signal input port to the output is the MC1496 gain parameter which is most often of interest to the designer. This gain has significance only when the lower differential amplifier is operated in a linear mode, but this includes most applications of the device.

As previously mentioned, the upper quad differential amplifier may be operated either in a linear or a saturated mode. Approximate gain expressions have been developed for the MC1496 for a low–level modulating signal input and the following carrier input conditions:

1) Low–level dc
2) High–level dc
3) Low–level ac
4) High–level ac

These gains are summarized in Figure 25, along with the frequency components contained in the output signal.

## APPLICATIONS INFORMATION

Double sideband suppressed carrier modulation is the basic application of the MC1496. The suggested circuit for this application is shown on the front page of this data sheet.

In some applications, it may be necessary to operate the MC1496 with a single dc supply voltage instead of dual supplies. Figure 26 shows a balanced modulator designed for operation with a single 12 Vdc supply. Performance of this circuit is similar to that of the dual supply modulator.

### AM Modulator

The circuit shown in Figure 27 may be used as an amplitude modulator with a minor modification.

All that is required to shift from suppressed carrier to AM operation is to adjust the carrier null potentiometer for the proper amount of carrier insertion in the output signal.

However, the suppressed carrier null circuitry as shown in Figure 27 does not have sufficient adjustment range. Therefore, the modulator may be modified for AM operation by changing two resistor values in the null circuit as shown in Figure 28.

### Product Detector

The MC1496 makes an excellent SSB product detector (see Figure 29).

This product detector has a sensitivity of 3.0 microvolts and a dynamic range of 90 dB when operating at an intermediate frequency of 9.0 MHz.

The detector is broadband for the entire high frequency range. For operation at very low intermediate frequencies down to 50 kHz the 0.1 μF capacitors on Pins 8 and 10 should be increased to 1.0 μF. Also, the output filter at Pin 12 can be tailored to a specific intermediate frequency and audio amplifier input impedance.

As in all applications of the MC1496, the emitter resistance between Pins 2 and 3 may be increased or decreased to adjust circuit gain, sensitivity, and dynamic range.

This circuit may also be used as an AM detector by introducing carrier signal at the carrier input and an AM signal at the SSB input.

The carrier signal may be derived from the intermediate frequency signal or generated locally. The carrier signal may be introduced with or without modulation, provided its level is sufficiently high to saturate the upper quad differential

amplifier. If the carrier signal is modulated, a 300 mVrms input level is recommended.

**Doubly Balanced Mixer**

The MC1496 may be used as a doubly balanced mixer with either broadband or tuned narrow band input and output networks.

The local oscillator signal is introduced at the carrier input port with a recommended amplitude of 100 mVrms.

Figure 30 shows a mixer with a broadband input and a tuned output.

**Frequency Doubler**

The MC1496 will operate as a frequency doubler by introducing the same frequency at both input ports.

Figures 31 and 32 show a broadband frequency doubler and a tuned output very high frequency (VHF) doubler, respectively.

**Phase Detection and FM Detection**

The MC1496 will function as a phase detector. High–level input signals are introduced at both inputs. When both inputs are at the same frequency the MC1496 will deliver an output which is a function of the phase difference between the two input signals.

An FM detector may be constructed by using the phase detector principle. A tuned circuit is added at one of the inputs to cause the two input signals to vary in phase as a function of frequency. The MC1496 will then provide an output which is a function of the input signal frequency.

## TYPICAL APPLICATIONS

**Figure 26. Balanced Modulator (12 Vdc Single Supply)**

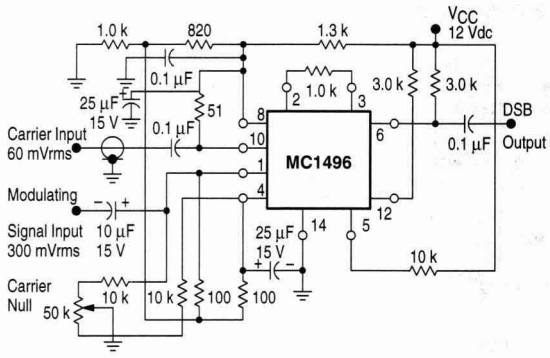



**Figure 27. Balanced Modulator–Demodulator**

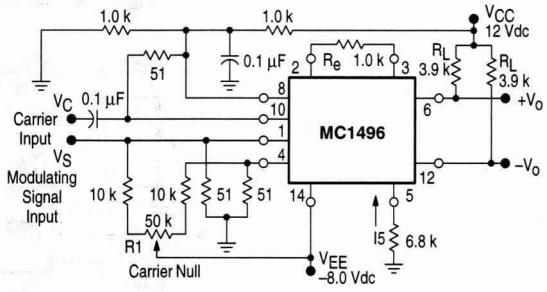



**Figure 28. AM Modulator Circuit**

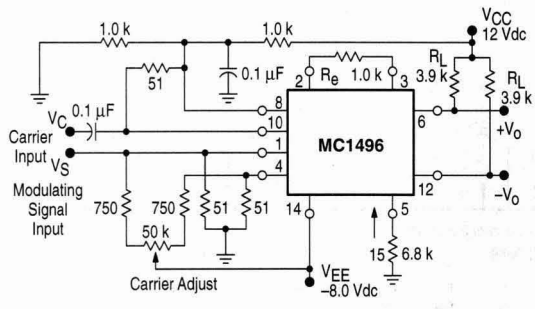
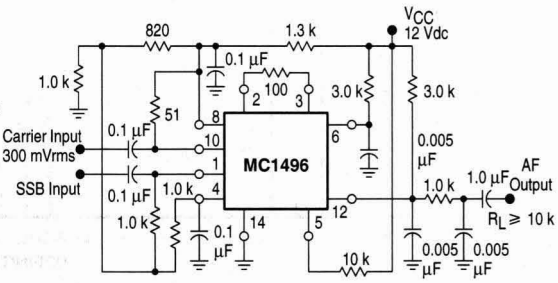
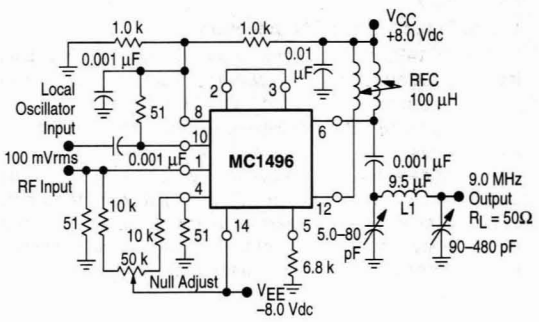



**Figure 29. Product Detector (12 Vdc Single Supply)**




8

**Figure 30. Doubly Balanced Mixer (Broadband Inputs, 9.0 MHz Tuned Output)**




L1 = 44 Turns AWG No. 28 Enameled Wire, Wound on Micrometals Type 44–6 Toroid Core.

**Figure 31. Low–Frequency Doubler**

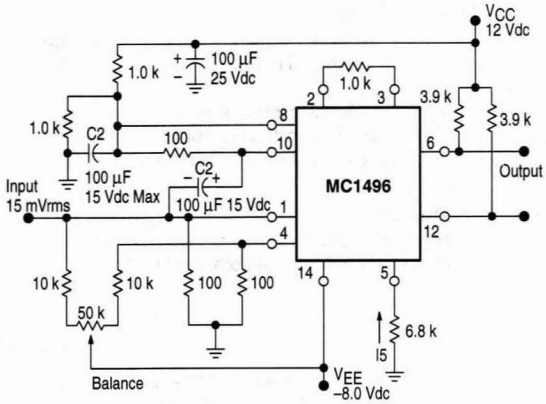
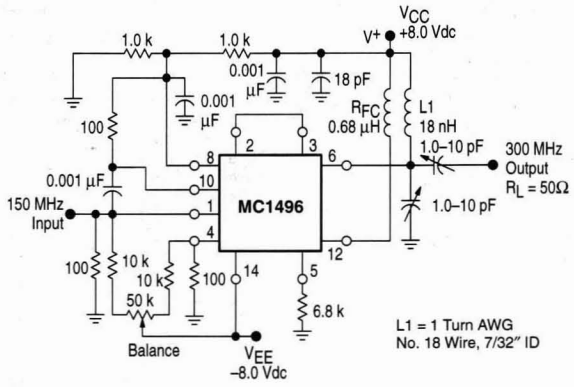
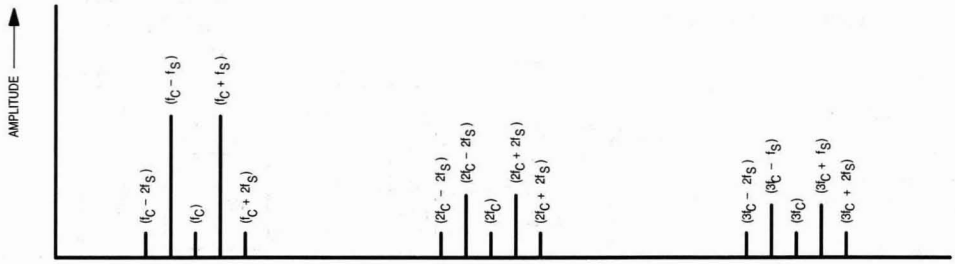



**Figure 32. 150 to 300 MHz Doubler**




L1 = 1 Turn AWG No. 18 Wire, 7/32″ ID




**DEFINITIONS**

| | | | |
|---|---|---|---|
| $f_C$ | Carrier Fundamental | $f_C \pm nf_S$ | Fundamental Carrier Sideband Harmonics |
| $f_S$ | Modulating Signal | $nf_C$ | Carrier Harmonics |
| $f_C \pm f_S$ | Fundamental Carrier Sidebands | $nf_C \pm nf_S$ | Carrier Harmonic Sidebands |

8

MOTOROLA

# Low Power FM Transmitter System

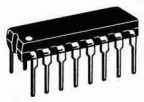
MC2833 is a one–chip FM transmitter subsystem designed for cordless telephone and FM communication equipment. It includes a microphone amplifier, voltage controlled oscillator and two auxiliary transistors.

- Wide Range of Operating Supply Voltage (2.8–9.0 V)
- Low Drain Current ($I_{CC}$ = 2.9 mA Typ)
- Low Number of External Parts Required
- – 30 dBm Power Output to 60 MHz Using Direct RF Output
- +10 dBm Power Output Attainable Using On–Chip Transistor Amplifiers
- Users Must Comply with Local Regulations on R.F. Transmission (FCC, DOT, P.T.T., etc)

**MC2833**

**LOW POWER FM TRANSMITTER SYSTEM**

**SEMICONDUCTOR TECHNICAL DATA**

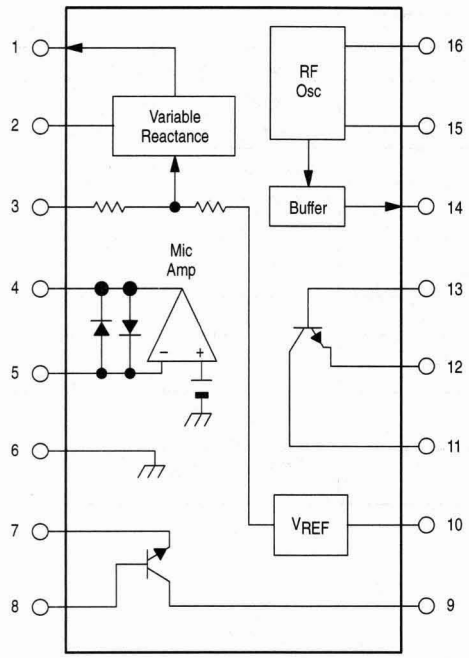


**P SUFFIX**
PLASTIC PACKAGE
CASE 648

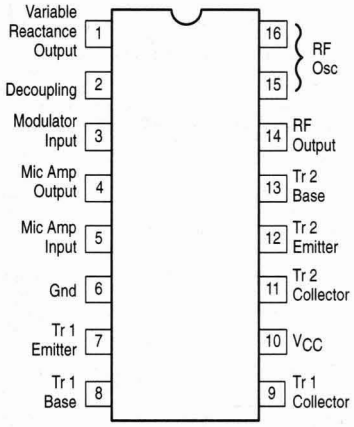
**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

8

**Representative Block Diagram**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC2833D | $T_A$ = – 30 to +75°C | SO–16 |
| MC2833P | | Plastic DIP |

## MAXIMUM RATINGS

| Ratings | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 10 (max) | V |
| Operating Supply Voltage Range | $V_{CC}$ | 2.8–9.0 | V |
| Junction Temperature | $T_J$ | + 150 | °C |
| Operating Ambient Temperature | $T_A$ | – 30 to + 75 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 150 | °C |

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 4.0 V, $T_A$ = 25°C, unless otherwise noted)

| Characteristics | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Drain Current (No input signal) | $I_{CC}$ | 10 | 1.7 | 2.9 | 4.3 | mA |
| **FM MODULATOR** | | | | | | |
| Output RF Voltage ($f_o$ = 16.6 MHz) | $V_{out}$ RF | 14 | 60 | 90 | 130 | mVrms |
| Output DC Voltage (No input signal) | Vdc | 14 | 2.2 | 2.5 | 2.8 | V |
| Modulation Sensitivity ($f_o$ = 16.6 MHz) ($V_{in}$ = 0.8 V to 1.2 V) | SEN | 3<br>14 | 7.0<br>– | 10<br>– | 15<br>– | Hz/mVdc |
| Maximum Deviation ($f_o$ = 16.6 MHz) ($V_{in}$ = 0 V to 2.0 V) | Fdev | 3<br>14 | 3.0<br>– | 5.0<br>– | 10<br>– | kHz |
| **MIC AMPLIFIER** | | | | | | |
| Closed Loop Voltage Gain ($V_{in}$ = 3.0 mVrms) ($f_{in}$ = 1.0 kHz) | $A_V$ | 4<br>5 | 27<br>– | 30<br>– | 33<br>– | dB |
| Output DC Voltage (No input signal) | $V_{out}$ dc | 4 | 1.1 | 1.4 | 1.7 | V |
| Output Swing Voltage ($V_{in}$ = 30 mVrms) ($f_{in}$ = 1.0 kHz) | $V_{out}$ p–p | 4 | 0.8 | 1.2 | 1.6 | Vp–p |
| Total Harmonic Distortion ($V_{in}$ = 3.0 mVrms) ($f_{in}$ = 1.0 kHz) | THD | 4 | – | 0.15 | 2.0 | % |

## AUXILIARY TRANSISTOR STATIC CHARACTERISTICS

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Collector Base Breakdown Voltage ($I_C$ = 5.0 μA) | $V_{(BR)CBO}$ | 15 | 45 | – | V |
| Collector Emitter Breakdown Voltage ($I_C$ = 200 μA) | $V_{(BR)CEO}$ | 10 | 15 | – | V |
| Collector Substrate Breakdown Voltage ($I_C$ = 50 μA) | $V_{(BR)CSO}$ | – | 70 | – | V |
| Emitter Base Breakdown Voltage ($I_E$ = 50 μA) | $V_{(BR)EBO}$ | – | 6.2 | – | V |
| Collector Base Cut Off Current ($V_{CB}$ = 10 V) ($I_E$ = 0) | $I_{CBO}$ | – | – | 200 | nA |
| DC Current Gain ($I_C$ = 3.0 mA) ($V_{CE}$ = 3.0 V) | $h_{FE}$ | 40 | 150 | – | – |

## AUXILIARY TRANSISTOR DYNAMIC CHARACTERISTICS

| | | | | | |
|---|---|---|---|---|---|
| Current Gain Bandwidth Product ($V_{CE}$ = 3.0 V) ($I_C$ = 3.0 mA) | $f_T$ | – | 500 | – | MHz |
| Collector Base Capacitance ($V_{CE}$ = 3.0 V) ($I_C$ = 0) | $C_{CB}$ | – | 2.0 | – | pF |
| Collector Substrate Capacitance ($V_{CS}$ = 3.0 V) ($I_C$ = 0) | $C_{CS}$ | – | 3.3 | – | pF |

8

**Figure 1. Test Circuit**

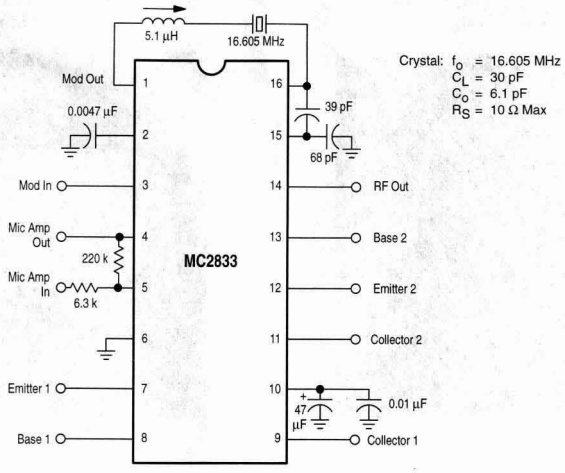
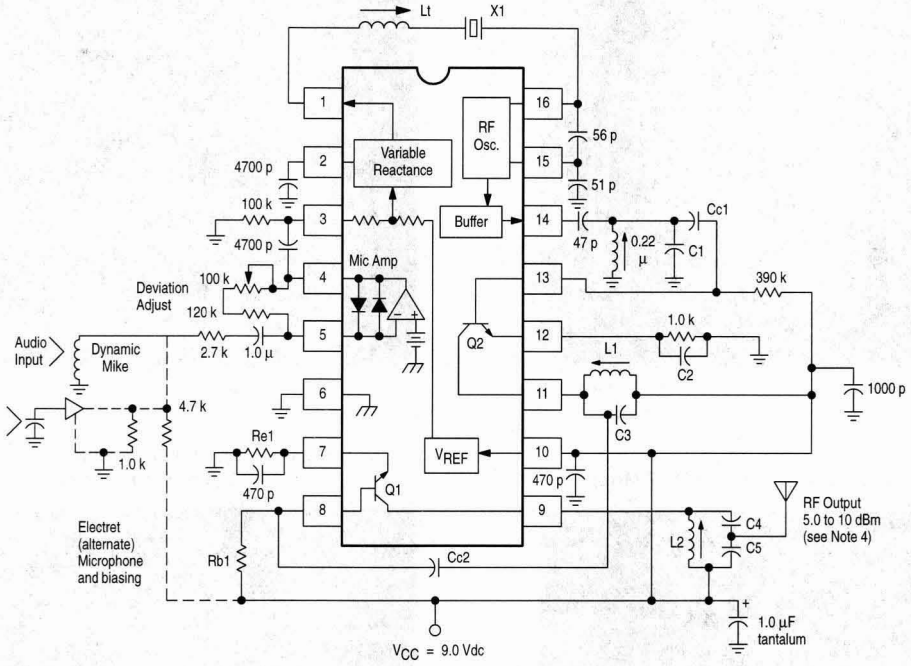



**Figure 2. Single Chip VHF Narrowband FM Transmitter**




**NOTES:**

1. Components versus output frequency:

| Output RF | X1 (MHz) | Lt (µH) | L1 (µH) | L2 (µH) | Re1 | Rb1 | Cc1 | Cc2 | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49.7 MHz | 16.5667 | 3.3–4.7 | 0.22 | 0.22 | 330 | 390 k | 33 p | 33 p | 33 p | 470 p | 33 p | 47 p | 220 p |
| 76 MHz | 12.6000 | 5.1 | 0.22 | 0.22 | 150 | 300 k | 68 p | 10 p | 68 p | 470 p | 12 p | 20 p | 120 p |
| 144.6 MHz | 12.05 | 5.6 | 0.15 | 0.10 | 150 | 220 k | 47 p | 10 p | 68 p | 1000 p | 18 p | 12 p | 33 p |

2. Crystal X1 is fundamental mode, calibrated for parallel resonance with a 32 pF load. The final output frequency is generated by frequency multiplication within the MC2833 IC. The RF output buffer (Pin 14) and Q2 transistor are used as a frequency tripler and doubler, respectively, in the 76 and 144.6 MHz transmitters. The Q1 output transistor is a linear amplifier in the 49.7 MHz and 76 MHz transmitters, and a frequency doubler in the 144.6 MHz transmitter.
3. All coils used are 7 mm shielded inductors, CoilCraft series M1175A, M1282A–M1289A, M1312A or equivalent.
4. Power output is ≈ + 10 dBm for 49.7 MHz and 76 MHz transmitters, and ≈ + 5.0 dBm for the 144.6 MHz transmitter at $V_{CC}$ = 8.0 V. Power output drops with lower $V_{CC}$.
5. All capacitors in microfarads, inductors in Henries and resistors in Ohms unless otherwise specified.
6. Other frequency combinations may be set–up by simple scaling of the 3 examples shown.

Figure 3. Buffer/Multiplier (x3, Pin 14)
(16 MHz Fundamental)

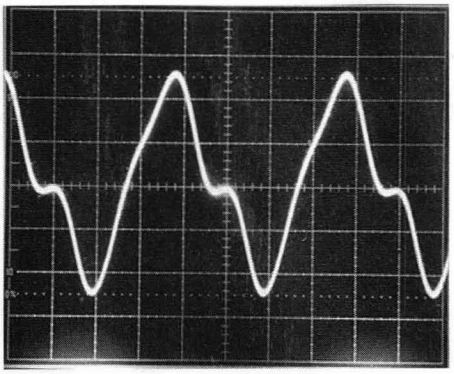


Figure 4. Input to Doubler (Pin 13)
(49.7 MHz x 3 Component)

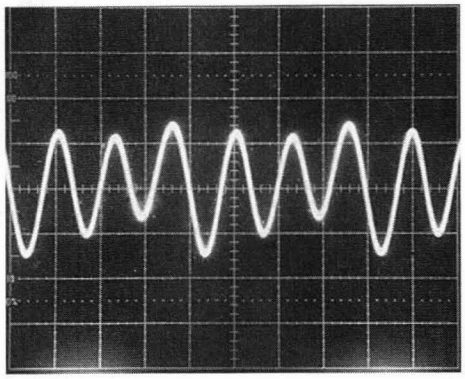


Figure 5. Doubler Output 76 MHz (Pin 11)

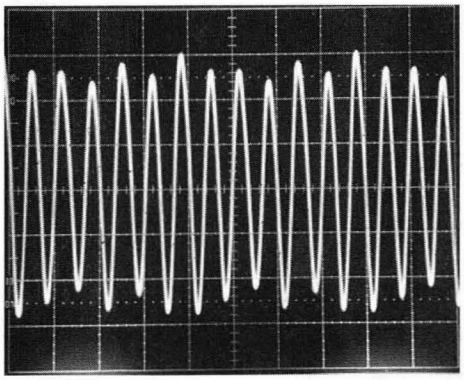


Figure 6. Spectrum

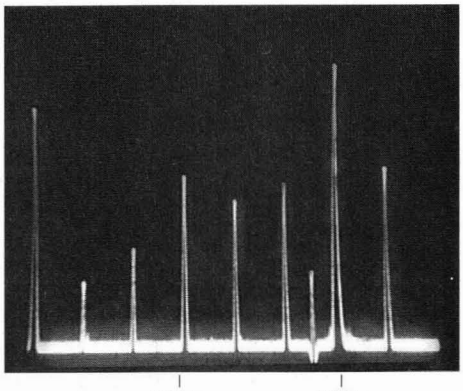



Figure 7. Output Spectrum (49.7 MHz)

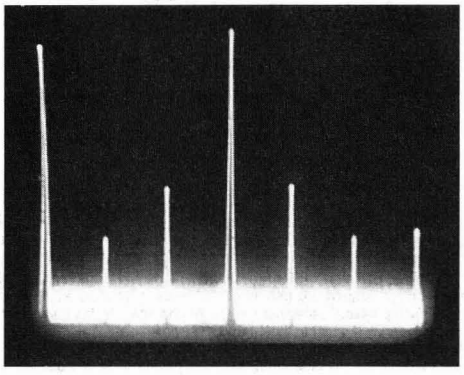



Figure 8. Modulation Spectrum
(1.0 kHz Showing Carrier Null)

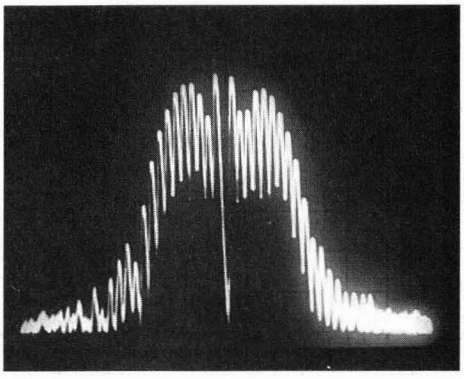


Figure 9. 144.6 MHz/x12 Multiplier

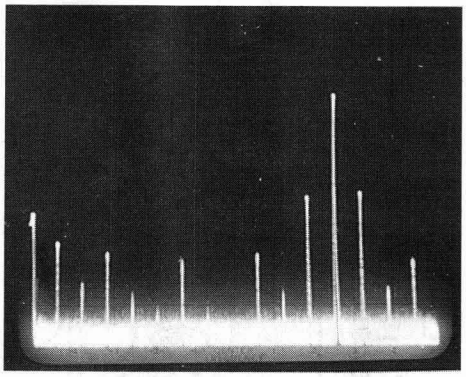


Figure 10. Circuit Side View

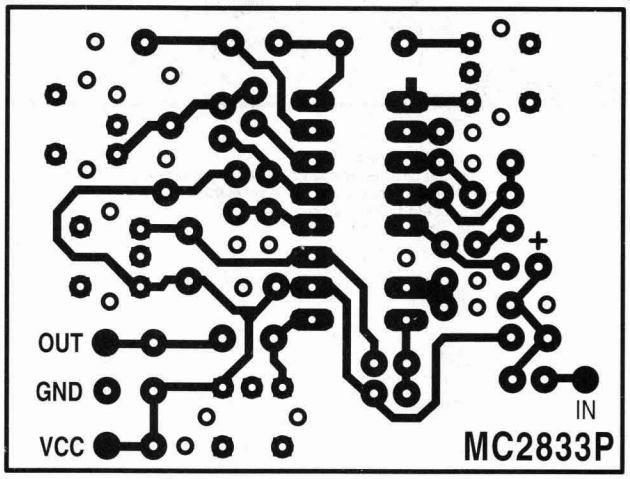



Figure 11. Ground Plane on Component Side

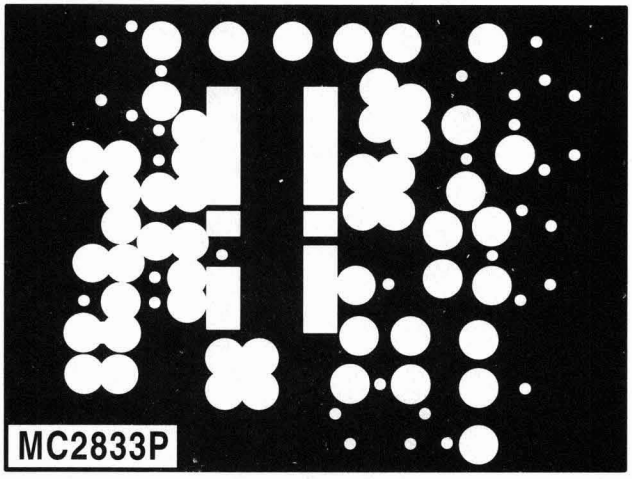
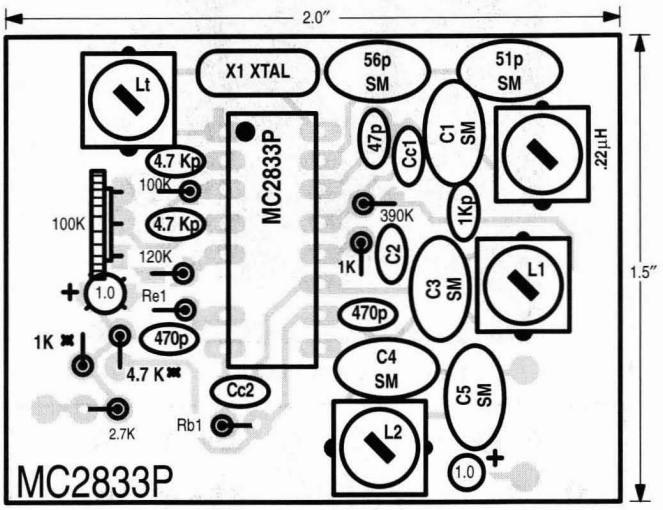


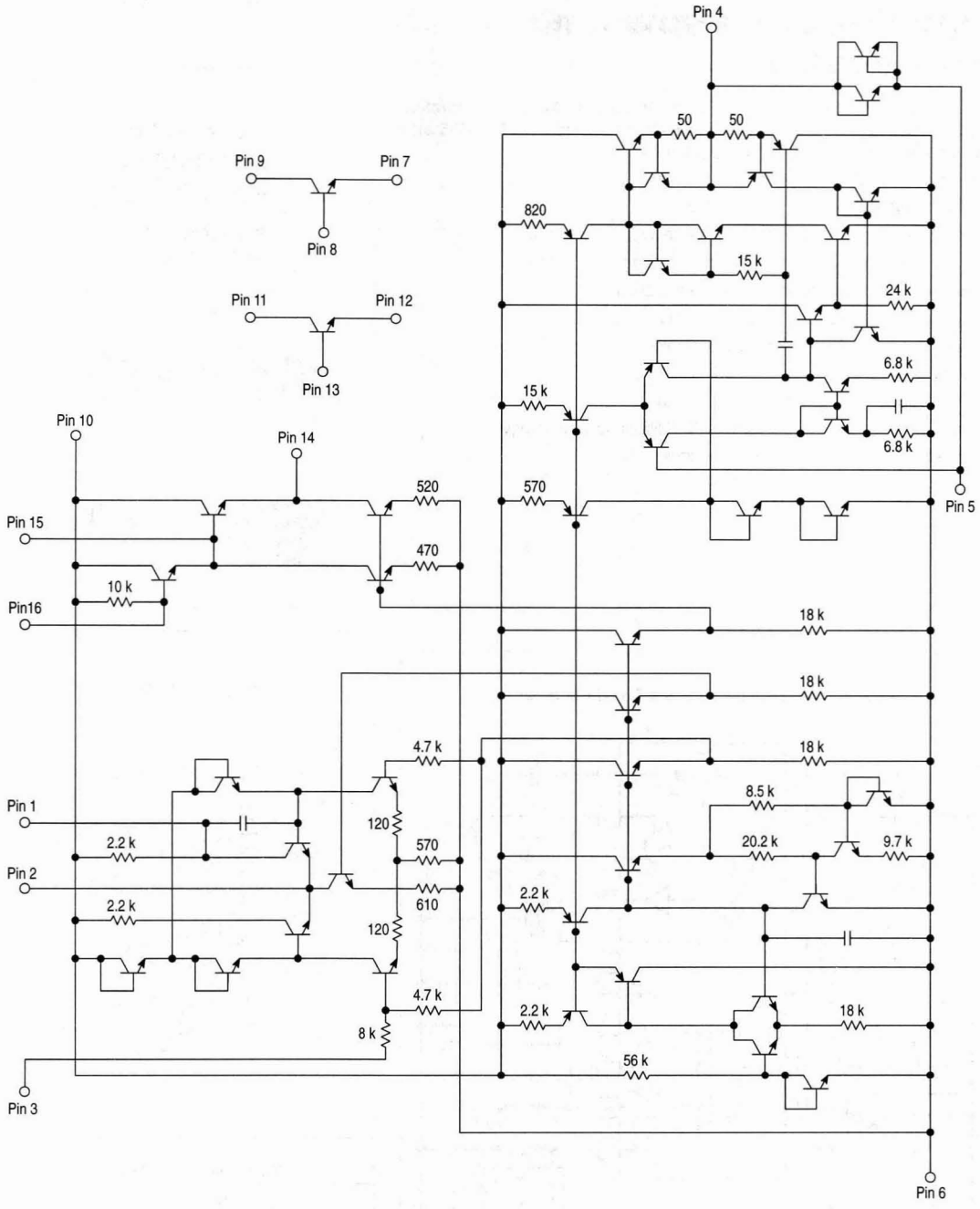
**Figure 12. Component View**




**NOTES:**
- Positive artwork provided.
- Drill holes must be plated to ensure making all ground ($V_{EE}$) connections!
- Resistors labelled * are used for biasing of electret microphone if used.
- Capacitors labelled "SM" are silver mica.
- Final board size 1.5″ × 2.0″.

8

**Figure 13. Circuit Schematic**




8

MOTOROLA

# Low Power Narrowband FM Receiver

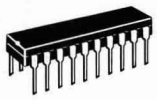
. . . includes dual FM conversion with Oscillators, Mixers, Quadrature Discriminator, and Meter Drive/Carrier Detect Circuitry. The MC3335 also has a comparator circuit for FSK detection.

- Complete Dual Conversion Circuitry
- Low Voltage: $V_{CC}$ = 2.0 to 6.0 Vdc
- Low Drain Current (Typical 3.6 mA with $V_{CC}$ = 3.0 Vdc)
- Excellent Sensitivity: – 3.0 dB Input Limiting = 0.7 μV
- Externally Adjustable Carrier Detect Function
- Separate Data Shaping Output Circuitry
- Data Rate Up to 35000 Baud Detectable
- 60 dB RSSI Range
- Low Number of External Parts Required
- Manufactured in Motorola's MOSAIC® Process Technology
- MC13135 is Preferred for New Designs

**MC3335**

**LOW POWER DUAL CONVERSION FM RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

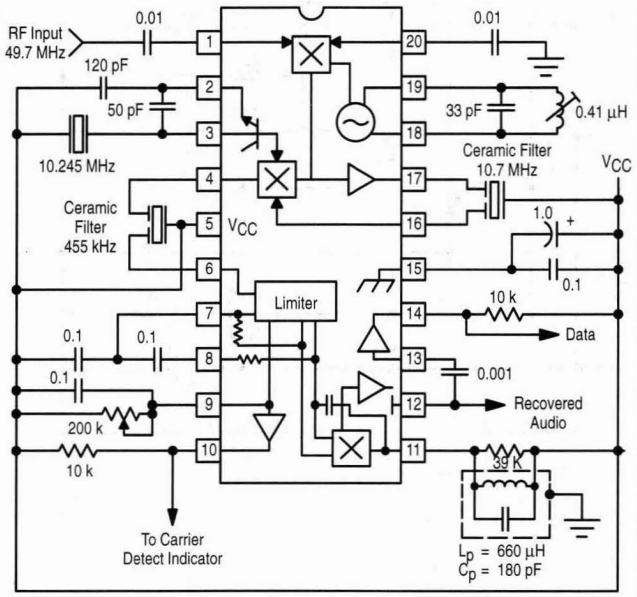


**P SUFFIX**
PLASTIC PACKAGE
CASE 738

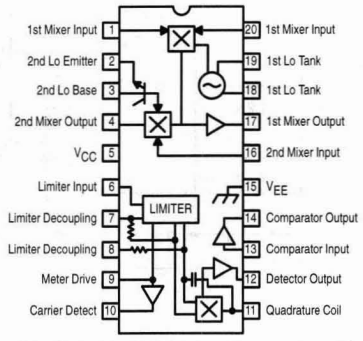
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

8

**Simplified Application as a Fixed Receiver**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3335DW | $T_A$ = – 40 to +85°C | SO–20 |
| MC3335P | | Plastic DIP |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 5 | $V_{CC(max)}$ | 7.0 | Vdc |
| Operating Supply Voltage Range (Recommended) | 5 | $V_{CC}$ | 2.0 to 6.0 | Vdc |
| Input Voltage ($V_{CC}$ > 5.0 Vdc) | 1,20 | V1–20 | 1.0 | Vrms |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | – | $T_A$ | – 40 to + 85 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $f_o$ = 49.7 MHz, Deviation = 3.0 kHz, $T_A$ = 25°C, test circuit of Figure 2, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Drain Current | 5 | – | 4.5 | 7.0 | mAdc |
| Input for – 3.0 dB Limiting | – | – | 0.7 | 2.0 | µVrms |
| Recovered Audio (RF Signal Level = 1.0 mV) | 12 | – | 250 | – | mVrms |
| Noise Output (RF Signal Level = 0 mV) | 12 | – | 250 | – | mVrms |
| Carrier Detect Threshold (below $V_{CC}$) | 9 | – | 0.64 | – | Vdc |
| Meter Drive Slope | 9 | – | 100 | – | µA/dB |
| Input for 20 dB (S+N/N) | – | – | 1.3 | – | µVrms |
| First Mixer 3rd Order Intercept (Input) | – | – | – 20 | – | dBm |
| First Mixer Input Resistance ($R_p$) | – | – | 690 | – | Ω |
| First Mixer Input Capacitance ($C_p$) | – | – | 7.2 | – | pF |
| First Mixer Conversion Voltage Gain | – | – | 18 | – | dB |
| Second Mixer Conversion Voltage Gain | – | – | 21 | – | dB |
| Detector Output Resistance | 12 | – | 1.4 | – | kΩ |

8

**Figure 1. Test Circuit**

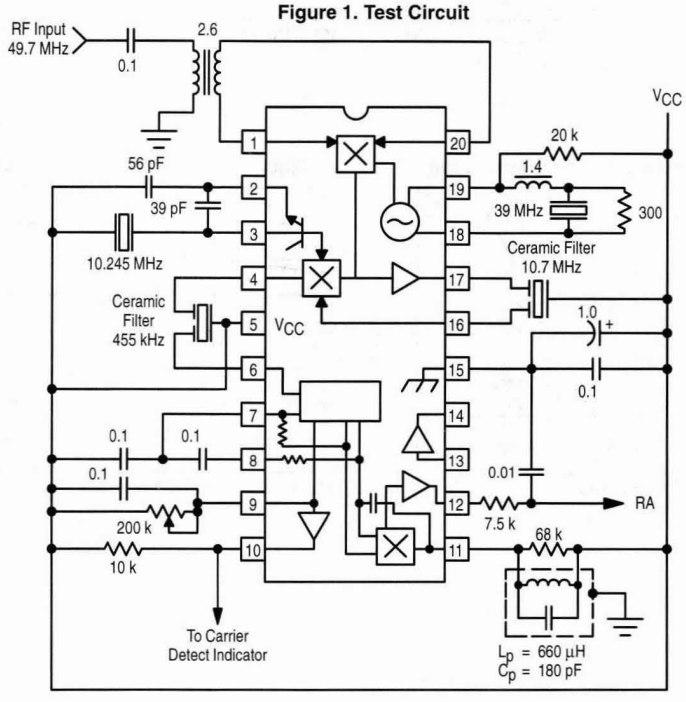


**Figure 2. $I_{meter}$ versus Input**

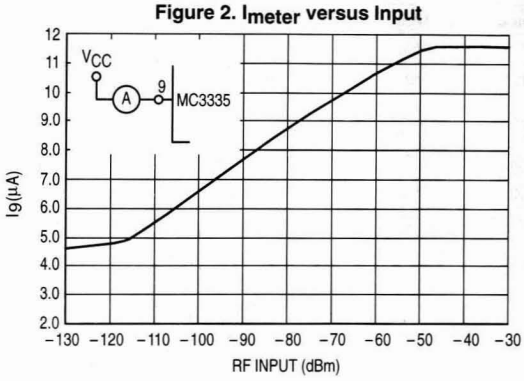



**Figure 3. Drain Current, Recovered Audio versus Supply**

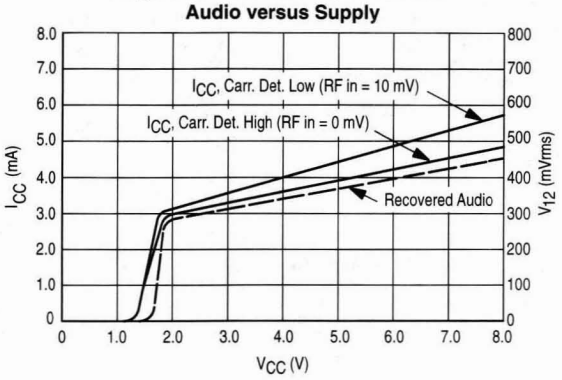



**Figure 4. (S + N), N of 2nd Mixer**

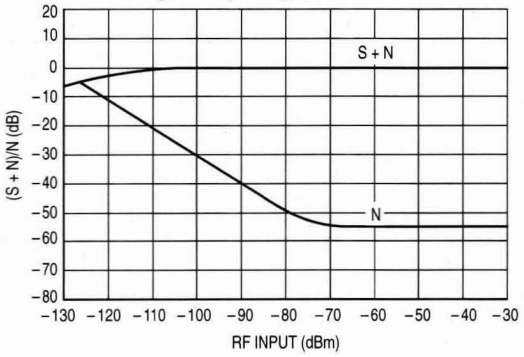



**Figure 5. (S + N)/N versus Input**

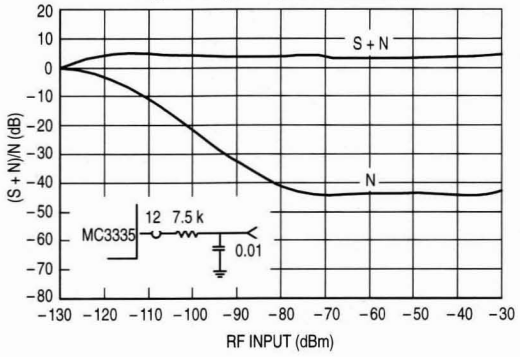



**Figure 6. 1st Mixer 3rd Order Intermodulation**

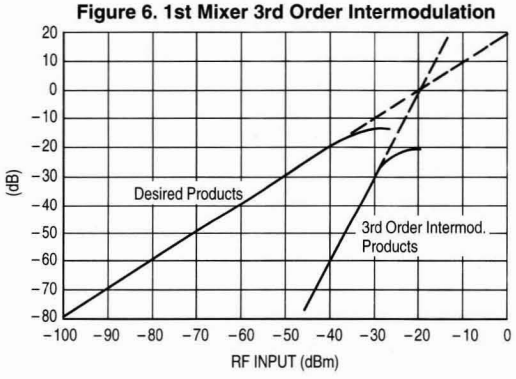
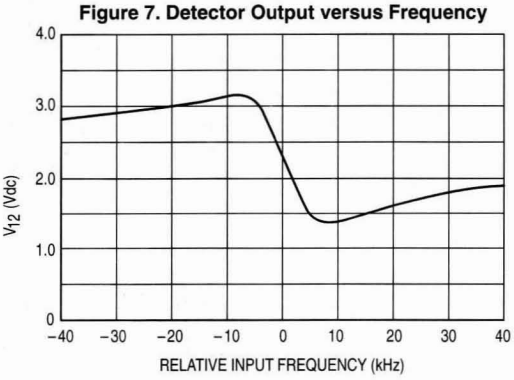



**Figure 7. Detector Output versus Frequency**




8

## CIRCUIT DESCRIPTION

The MC3335 is a complete FM narrowband receiver from antenna input to audio preamp output. The low voltage dual conversion design yields low power drain, excellent sensitivity and good image rejection in narrowband voice and data link applications.

In the typical application diagram, the first mixer amplifies the signal and converts the RF input to 10.7 MHz. This IF signal is filtered externally and fed into the second mixer, which further amplifies the signal and converts it to a 455 kHz IF signal. After external bandpass filtering, the low IF is fed into the limiting amplifier and detection circuitry. The audio is recovered using a conventional quadrature detector. Twice–IF filtering is provided internally.

The input signal level is monitored by meter drive circuitry which detects the amount of limiting in the limiting amplifier. The voltage at the meter drive pin determines the state of the carrier detect output which is active low.

## APPLICATIONS INFORMATION

The first local oscillator can be run using a free running LC tank, as a VCO using PLL synthesis, or driven from an external crystal oscillator. At higher $V_{CC}$ values (6.0 to 7.0 V), it has been run to 170 MHz. The second local oscillator is a common base Colpitts type which is typically run at 10.245 MHz under crystal control.

The mixers are doubly balanced to reduce spurious responses. The first and second mixers have conversion gains of 18 dB and 22 dB (typical), respectively. Mixer gain is stable with respect to supply voltage. For both conversions, the mixer impedances and pin layout are designed to allow the user to employ low cost, readily available ceramic filters. Overall sensitivity is shown in Figure 5. The input level for 20 dB (S + N)/N is 1.3 μV using the two–pole post–detection filter as demonstrated.

Following the first mixer, a 10.7 MHz ceramic bandpass filter is recommended. The 10.7 MHz filtered signal is then fed into one second mixer input pin, the other input pin being connected to $V_{CC}$. Pin 5 ($V_{CC}$) is treated as a common point for emitter–driven signals.

The 455 kHz IF is typically filtered using a ceramic bandpass filter, then fed into the limiter input pin. The limiter has 10 μV sensitivity for –3.0 dB limiting, flat to 1.0 MHz.

The output of the limiter is internally connected to the quadrature detector, including a quadrature capacitor. A parallel LC tank is needed externally from Pin 11 to VCC. A 39 kΩ shunt resistance is included which determines the peak separation of the quadrature detector; a smaller value will increase the spacing and linearity but decrease recovered audio and sensitivity.

A data shaping circuit is available and can be coupled to the recovered audio output of Pin 12. The circuit is a comparator which is designed to detect zero crossings of FSK modulation. Data rates of up to 35000 baud are detectable using the typical application. Hysteresis is available by connecting a high–valued resistor from Pin 13 to Pin 14. Values below 120 kΩ are not recommended as the input signal cannot overcome the hysteresis.

The meter drive circuitry detects input signal level by monitoring the limiting of the limiting amplifier stages. Figure 2 shows the unloaded current at Pin 9 versus input power. The meter drive current can be used directly (RSSI) or can be used to trip the carrier detect circuit at a specified input power. To do this, pick an RF trip level in dBm. Read the corresponding current from Figure 2 and pick a resistor such that:

$$R9 = 0.64\ Vdc / I9$$

Hysteresis is available by connecting a high–valued resistor RH between Pin 9 and 10. The formula is:

$$Hysteresis = V_{CC}/(RH \times 10^{-7})\ dB$$

8

MOTOROLA

# MC3356

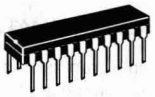
## Wideband FSK Receiver

The MC3356 includes Oscillator, Mixer, Limiting IF Amplifier, Quadrature Detector, Audio Buffer, Squelch, Meter Drive, Squelch Status output, and Data Shaper comparator. The MC3356 is designed for use in digital data communciations equipment.

- Data Rates up to 500 kilobaud
- Excellent Sensitivity: – 3 dB Limiting Sensitivity
  30 μVrms @ 100 MHz
- Highly Versatile, Full Function Device, yet Few External Parts are Required
- Down Converter Can be Used Independently — Similar to NE602

**WIDEBAND FSK RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

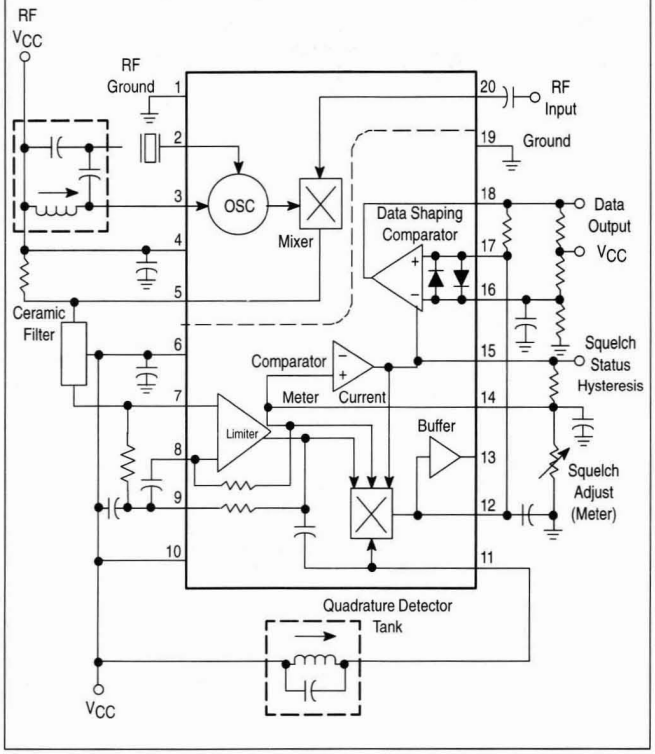


**P SUFFIX**
PLASTIC PACKAGE
CASE 738

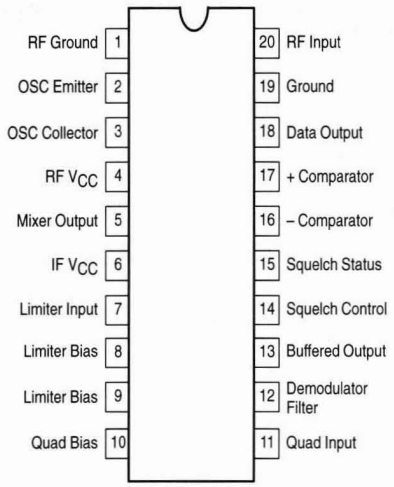
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

8

**Figure 1. Representative Block Diagram**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3356DW | $T_A$ = – 40 to +85°C | SO–20L |
| MC3356P | | Plastic DIP |

## MAXIMUM RATINGS

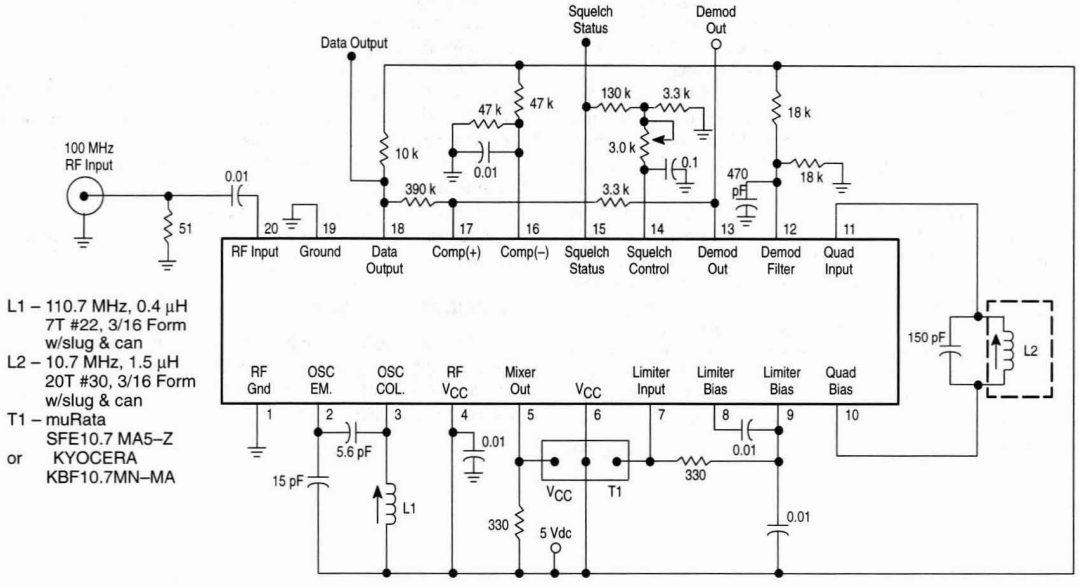
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC(max)}$ | 15 | Vdc |
| Operating Power Supply Voltage Range (Pins 6, 10) | $V_{CC}$ | 3.0 to 9.0 | Vdc |
| Operating RF Supply Voltage Range (Pin 4) | RF $V_{CC}$ | 3.0 to 12.0 | Vdc |
| Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | $T_A$ | – 40 to + 85 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to + 150 | °C |
| Power Dissipation, Package Rating | $P_D$ | 1.25 | W |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $f_o$ = 100 MHz, $f_{osc}$ = 110.7 MHz, $\Delta f$ = ±75 kHz, $f_{mod}$ = 1.0 kHz, 50 Ω source, $T_A$ = 25°C, test circuit of Figure 2, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Drain Current Total, RF $V_{CC}$ and $V_{CC}$ | – | 20 | 25 | mAdc |
| Input for – 3 dB limiting | – | 30 | – | µVrms |
| Input for 50 dB quieting $\left(\frac{S+N}{N}\right)$ | – | 60 | – | µVrms |
| Mixer Voltage Gain, Pin 20 to Pin 5 | 2.5 | – | – | |
| Mixer Input Resistance, 100 MHz | – | 260 | – | Ω |
| Mixer Input Capacitance, 100 MHz | – | 5.0 | – | pF |
| Mixer/Oscillator Frequency Range (Note 1) | – | 0.2 to 150 | – | MHz |
| IF/Quadrature Detector Frequency Range (Note 1) | – | 0.2 to 50 | – | MHz |
| AM Rejection (30% AM, RF $V_{in}$ = 1.0 mVrms) | – | 50 | – | dB |
| Demodulator Output, Pin 13 | – | 0.5 | – | Vrms |
| Meter Drive | – | 7.0 | – | µA/dB |
| Squelch Threshold | – | 0.8 | – | Vdc |

**NOTE:** 1. Not taken in Test Circuit of Figure 2; new component values required.

**Figure 2. Test Circuit**




L1 – 110.7 MHz, 0.4 µH
7T #22, 3/16 Form
w/slug & can
L2 – 10.7 MHz, 1.5 µH
20T #30, 3/16 Form
w/slug & can
T1 – muRata
SFE10.7 MA5–Z
or KYOCERA
KBF10.7MN–MA

8

**Figure 3. Output Components of Signal, Noise, and Distortion**

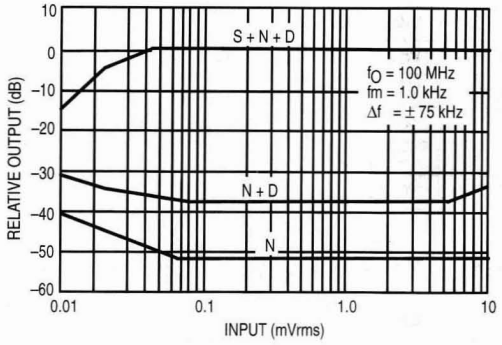
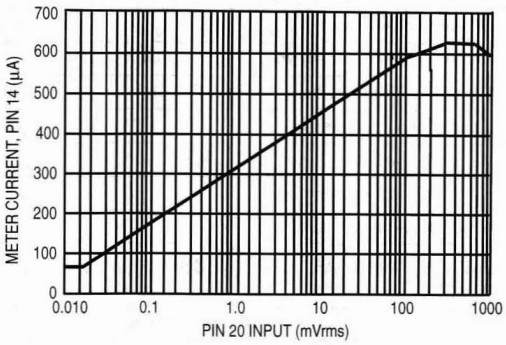



**Figure 4. Meter Current versus Signal Input**




## GENERAL DESCRIPTION

This device is intended for single and double conversion VHF receiver systems, primarily for FSK data transmission up to 500 K baud (250 kHz). It contains an oscillator, mixer, limiting IF, quadrature detector, signal strength meter drive, and data shaping amplifier.

The oscillator is a common base Colpitts type which can be crystal controlled, as shown in Figure 1, or L–C controlled as shown in the other figures. At higher $V_{CC}$, it has been operated as high as 200 MHz. A mixer/oscillator voltage gain of 2 up to approximately 150 MHz, is readily achievable.

The mixer functions well from an input signal of 10 μVrms, below which the squelch is unpredictable, up to about 10 mVrms, before any evidence of overload. Operation up to 1.0 Vrms input is permitted, but non–linearity of the meter output is incurred, and some oscillator pulling is suspected. The AM rejection above 10 mVrms is degraded.

The limiting IF is a high frequency type, capable of being operated up to 50 MHz. It is expected to be used at 10.7 MHz in most cases, due to the availability of standard ceramic resonators. The quadrature detector is internally coupled to the IF, and a 5.0 pF quadrature capacitor is internally provided. The –3dB limiting sensitivity of the IF itself is approximately 50 μV (at Pin 7), and the IF can accept signals up to 1.0 Vrms without distortion or change of detector quiescent dc level.

The IF is unusual in that each of the last 5 stages of the 6 state limiter contains a signal strength sensitive, current sinking device. These are parallel connected and buffered to produce a signal strength meter drive which is fairly linear for IF input signals of 10 μV to 100 mVrms (see Figure 4).

A simple squelch arrangement is provided whereby the meter current flowing through the meter load resistance flips a comparator at about 0.8 Vdc above ground. The signal strength at which this occurs can be adjusted by changing the meter load resistor. The comparator (+) input and output are available to permit control of hysteresis. Good positive action can be obtained for IF input signals of above 30 μVrms. The 130 kΩ resistor shown in the test circuit provides a small amount of hysteresis. Its connection between the 3.3 k resistor to ground and the 3.0 k pot, permits adjustment of squelch level without changing the amount of hysteresis.

The squelch is internally connected to both the quadrature detector and the data shaper. The quadrature detector output, when squelched, goes to a dc level approximately equal to the zero signal level unsquelched. The squelch causes the data shaper to produce a high ($V_{CC}$) output.

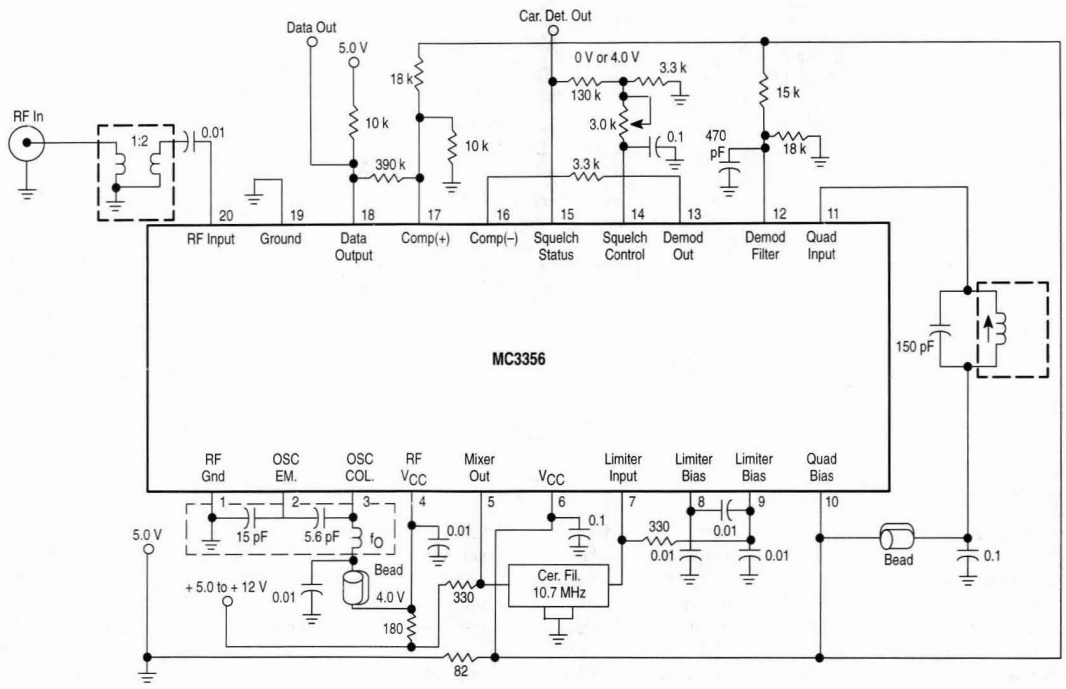
The data shaper is a complete "floating" comparator, with back to back diodes across its inputs. The output of the quadrature detector can be fed directly to either input of this amplifier to produce an output that is either at $V_{CC}$ or $V_{EE}$, depending upon the received frequency. The impedance of the biasing can be varied to produce an amplifier which "follows" frequency detuning to some degree, to prevent data pulse width changes.

When the data shaper is driven directly from the demodulator output, Pin 13, there may be distortion at Pin 13 due to the diodes, but this is not important in the data application. A useful note in relating high/low input frequency to logic state: low IF frequency corresponds to low demodulator output. If the oscillator is above the incoming RF frequency, then high RF frequency will produce a logic low (input to (+) input of Data Shaper as shown in Figures 1 and 2).

## APPLICATION NOTES

The MC3356 is a high frequency/high gain receiver that requires following certain layout techniques in designing a stable circuit configuration. The objective is to minimize or eliminate, if possible, any unwanted feedback.

**Figure 5. Application with Fixed Bias on Data Shaper**




8

## APPLICATION NOTES (continued)

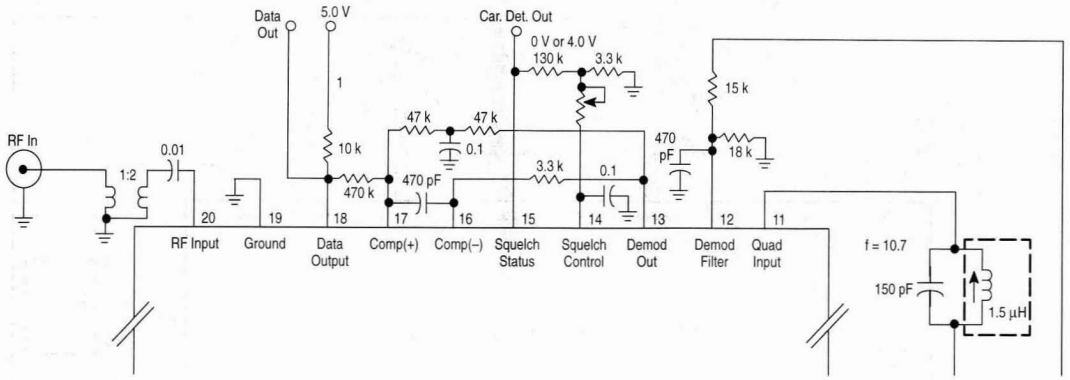
Shielding, which includes the placement of input and output components, is important in minimizing electrostatic or electromagnetic coupling. The MC3356 has its pin connections such that the circuit designer can place the critical input and output circuits on opposite ends of the chip. Shielding is normally required for inductors in tuned circuits.

The MC3356 has a separate $V_{CC}$ and ground for the RF and IF sections which allows good external circuit isolation by minimizing common ground paths.

Note that the circuits of Figures 1 and 2 have RF, Oscillator, and IF circuits predominantly referenced to the plus supply rails. Figure 5, on the other hand, shows a suitable means of ground referencing. The two methods produce identical results when carefully executed. It is important to treat Pin 19 as a ground node for either approach. The RF input should be "grounded" to Pin 1 and then the input and the mixer/oscillator grounds (or RF $V_{CC}$ bypasses) should be connected by a low inductance path to Pin 19. IF and detector sections should also have their bypasses returned by a **separate** path to Pin 19. $V_{CC}$ and RF $V_{CC}$ can be decoupled to minimize feedback, although the configuration of Figure 2 shows a successful implementation on a common 5.0 V supply. Once again, the message is: define a supply node and a ground node and return each section to those nodes by separate, low impedance paths.

The test circuit of Figure 2 has a 3 dB limiting level of 30 μV which can be lowered 6 db by a 1:2 untuned transformer at the input as shown in Figures 5 and 6. For applications that require additional sensitivity, an RF amplifier can be added, but with no greater than 20 db gain. This will give a 2.0 to 2.5 μV sensitivity and any additional gain will reduce receiver dynamic range without improving its sensitivity. Although the test circuit operates at 5.0 V, the mixer/oscillator optimum performance is at 8.0 V to 12 V. A minimum of 8.0 V is recommended in high frequency applications (above 150 MHz), or in PLL applications where the oscillator drives a prescaler.

**Figure 6. Application with Self–Adjusting Bias on Data Shaper**

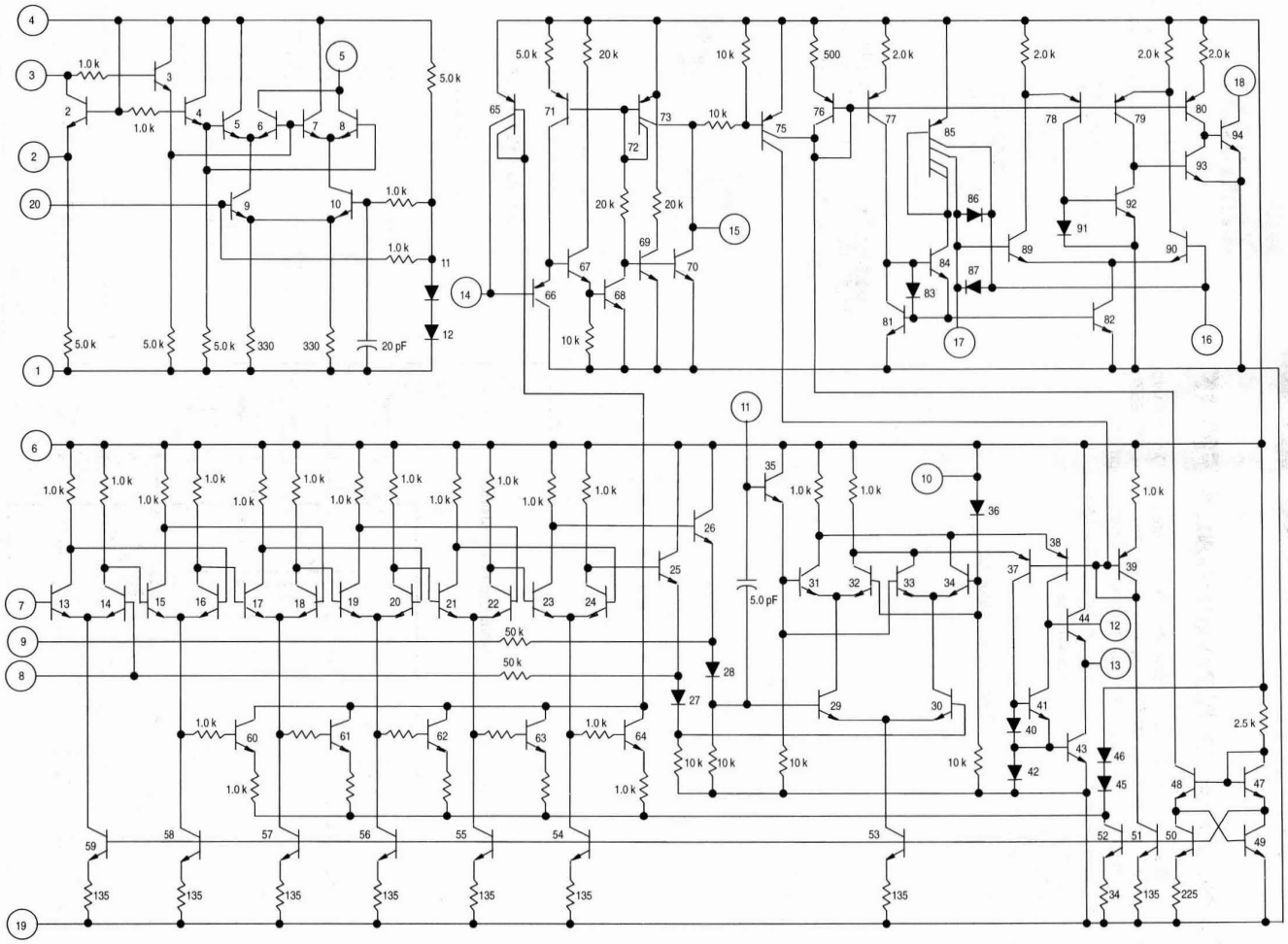



**APPLICATION NOTES (continued)**

Depending on the external circuit, inverted or noninverted data is available at Pin 18. Inverted data makes the higher frequency in the FSK signal a "one" when the local oscillator is above the incoming RF. Figure 5 schematic shows the comparator with hysteresis. In this circuit the dc reference voltage at Pin 17 is about the same as the demodulated output voltage (Pin 13) when no signal is present. This type circuit is preferred for systems where the data rates can drop to zero. Some systems have a low frequency limit on the data rate, such as systems using the MC3850 ACIA that has a start or stop bit. This defines the low frequency limit that can appear in the data stream. Figure 5 circuit can then be changed to a circuit configuration as shown in Figure 6. In Figure 6 the reference voltage for the comparator is derived from the demodulator output through a low pass circuit where $\tau$ is much lower than the lowest frequency data rate. This and similar circuits will compensate for small tuning changes (or drift) in the quadrature detector.

Squelch status (Pin 15) goes high (squelch off) when the input signal becomes greater than some preset level set by the resistance between Pin 14 and ground. Hysteresis is added to the circuit externally by the resistance from Pin 14 to Pin 15.

**Figure 7. Internal Schematic**



MOTOROLA

# Low Power Narrowband FM IF

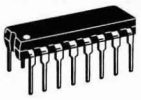
. . . includes Oscillator, Mixer, Limiting Amplifier, Quadrature Discriminator, Active Filter, Squelch, Scan Control, and Mute Switch. The MC3357 is designed for use in FM dual conversion communications equipment.

- Low Drain Current (3.0 mA (Typical) @ $V_{CC}$ = 6.0 Vdc)
- Excellent Sensitivity: Input Limiting Voltage – (– 3.0 dB) = 5.0 μV (Typical)
- Low Number of External Parts Required
- Recommend MC3372 for Replacement/Upgrade

**MC3357**

**LOW POWER FM IF**

**SEMICONDUCTOR TECHNICAL DATA**

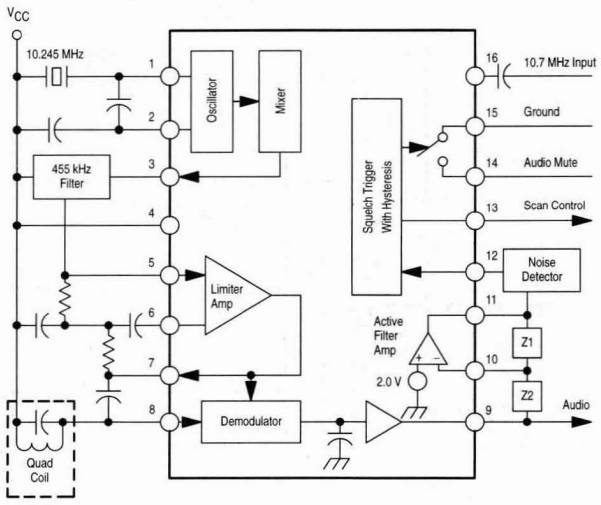


**P SUFFIX**
PLASTIC PACKAGE
CASE 648

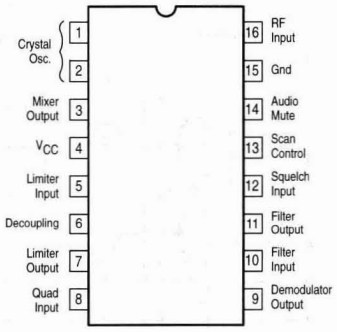
**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

8

**Figure 1. Representative Block Diagram**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3357D | $T_A$ = – 30 to +70°C | SO–16 |
| MC3357P | | Plastic DIP |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

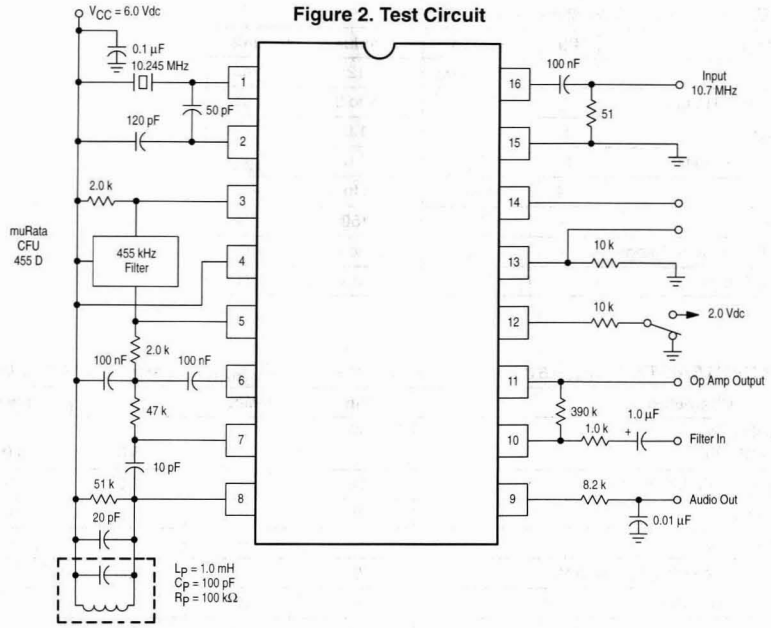
| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4 | $V_{CC}$(max) | 12 | Vdc |
| Operating Supply Voltage Range | 4 | $V_{CC}$ | 4 to 8 | Vdc |
| Detector Input Voltage | 8 | – | 1.0 | Vp–p |
| Input Voltage ($V_{CC}$ ≥ 6.0 Volts) | 16 | $V_{16}$ | 1.0 | $V_{RMS}$ |
| Mute Function | 14 | $V_{14}$ | –0.5 to 5.0 | $V_{pk}$ |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | – | $T_A$ | – 30 to + 70 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 6.0 Vdc, fo = 10.7 MHz, Δf = ± 3.0 kHz, $f_{mod}$ = 1.0 kHz, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Drain Current Squelch Off<br>Squelch On | 4 | –<br>– | 2.0<br>3.0 | –<br>5.0 | mA |
| Input Limiting Voltage (– 3 dB Limiting) | 16 | – | 5.0 | 10 | μV |
| Detector Output Voltage | 9 | – | 3.0 | – | Vdc |
| Detector Output Impedance | – | – | 400 | – | Ω |
| Recovered Audio Output Voltage ($V_{in}$ = 10 mV) | 9 | 200 | 350 | – | mVrms |
| Filter Gain (10 kHz) ($V_{in}$ = 5 mV) | – | 40 | 46 | – | dB |
| Filter Output Voltage | 11 | 1.8 | 2.0 | 2.5 | Vdc |
| Trigger Hysteresis | – | – | 100 | – | mV |
| Mute Function Low | 14 | – | 15 | 50 | Ω |
| Mute Function High | 14 | 1.0 | 10 | – | MΩ |
| Scan Function Low (Mute Off)<br>($V_{12}$ = 2 Vdc) | 13 | – | 0 | 0.5 | Vdc |
| Scan Function High (Mute On)<br>($V_{12}$ = Gnd) | 13 | 5.0 | – | – | Vdc |
| Mixer Conversion Gain | 3 | – | 20 | – | dB |
| Mixer Input Resistance | 16 | – | 3.3 | – | kΩ |
| Mixer Input Capacitance | 16 | – | 2.2 | – | pF |

8

**Figure 2. Test Circuit**




8

## CIRCUIT DESCRIPTION

The MC3357 is a low power FM IF circuit designed primarily for use in voice communication scanning receivers.

The mixer–oscillator combination converts the input frequency (e.g., 10.7 MHz) down to 455 kHz, where, after external bandpass filtering, most of the amplification is done. The audio is recovered using a conventional quadrature FM detector. The absence of an input signal is indicated by the presence of noise above the desired audio frequencies. This "noise band" is monitored by an active filter and a detector. A squelch trigger circuit indicates the presence of a noise (or a tone) by an output which can be used to control scanning. At the same time, an internal switch is operated which can be used to mute the audio.

The oscillator is an internally–biased Colpitts type with the collector, base, and emitter connections at Pins 4, 1, and 2 respectively. A crystal can be used in place of the usual coil.

The mixer is doubly–balanced to reduce spurious responses. The input impedance at Pin 16 is set by a 3.0 kΩ internal biasing resistor and has low capacitance, allowing the circuit to be preceded by a crystal filter. The collector output at Pin 3 must be dc connected to B +, below which it can swing 0.5 V.

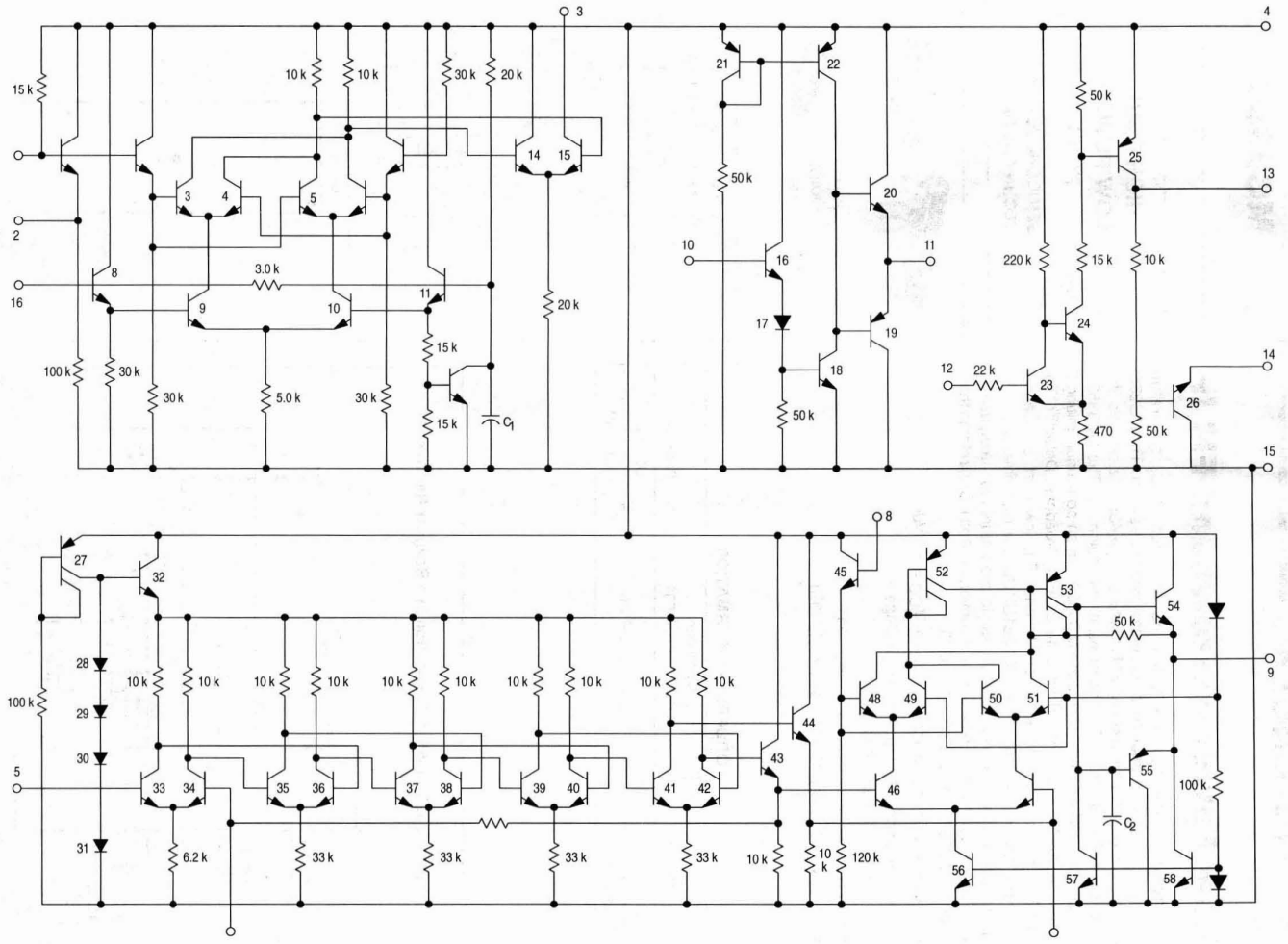
After suitable bandpass filtering (ceramic or LC), the signal goes to the input of a five–stage limiter at Pin 5. The output of the limiter at Pin 7 drives a multiplier, both internally directly, and externally through a quadrature coil, to detect the FM. The output at Pin 7 is also used to supply dc feedback to Pin 5. The other side of the first limiter stage is decoupled at Pin 6.

The recovered audio is partially filtered, then buffered, giving an impedance of around 400 Ω at Pin 9. The signal still requires de–emphasis, volume control and further amplification before driving a loudspeaker.

A simple inverting op amp is provided with an output at Pin 11 providing dc bias (externally) to the input at Pin 10 which is referred internally to 2.0 V. A filter can be made with external impedance elements to discriminate between frequencies. With an external AM detector, the filtered audio signal can be checked for the presence of noise above the normal audio band, or a tone signal. This information is applied to Pin 12.

An external positive bias to Pin 12 sets up the squelch trigger circuit such that Pin 13 is low at an impedance level of around 60 kΩ, and the audio mute (Pin 14) is open circuit. If Pin 12 is pulled down to 0.7 V by the noise or tone detector, Pin 13 will rise to approximately 0.5 Vdc below supply where it can support a load current of around 500 µA and Pin 14 is internally short–circuited to ground. There is 100 mV of hysteresis at Pin 12 to prevent jitter. Audio muting is accomplished by connecting Pin 14 to a high–impedance ground–reference point in the audio path between Pin 9 and the audio amplifier.

**Figure 3. Circuit Schematic**



MOTOROLA

# MC3359

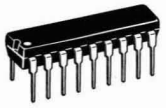
# Low Power Narrowband FM IF

. . . includes oscillator, mixer, limiting amplifier, AFC, quadrature discriminator, op/amp, squelch, scan control, and mute switch. The MC3359 is designed to detect narrowband FM signals using a 455 kHz ceramic filter for use in FM dual conversion communications equipment. The MC3359 is similar to the MC3357 except that the MC3359 has an additional limiting IF stage, an AFC output, and an opposite polarity Broadcast Detector. The MC3359 also requires fewer external parts. For low cost applications requiring $V_{CC}$ below 6.0 V, the MC3361BP,BD are recommended. For applications requiring a fixed, tuned, ceramic quadrature resonator, use the MC3357. For applications requiring dual conversion and RSSI, refer to these devices; MC3335, MC3362 and MC3363.

- Low Drain Current: 3.6 mA (Typical) @ $V_{CC}$ = 6.0 Vdc
- Excellent Sensitivity: Input Limiting Voltage – – 3.0 dB = 2.0 μV (Typical)
- Low Number of External Parts Required
- For Low Voltage and RSSI, use the MC3371

**HIGH GAIN LOW POWER FM IF**

**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 707

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3359DW | $T_A$ = –30 to +70°C | SO–20L |
| MC3359P | | Plastic DIP |

8

**Figure 1. Simplified Application in a Scanner Receiver**

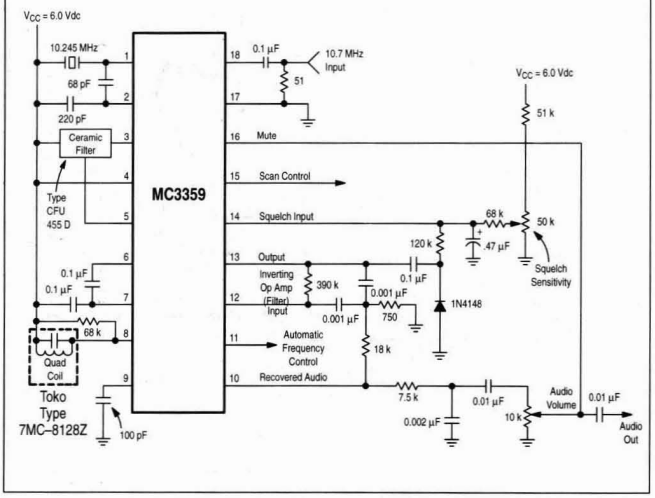
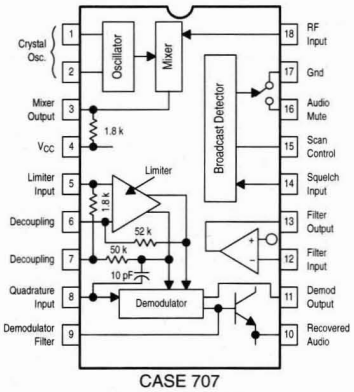
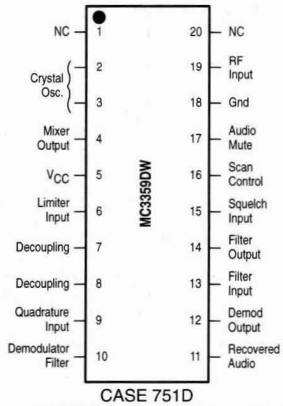



**Figure 2. Pin Connections and Functional Block Diagram**




CASE 707




CASE 751D

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4 | $V_{CC}$(max) | 12 | Vdc |
| Operating Supply Voltage Range | 4 | $V_{CC}$ | 6 to 9 | Vdc |
| Input Voltage ($V_{CC}$ ≥ 6.0 Volts) | 18 | $V_{18}$ | 1.0 | $V_{rms}$ |
| Mute Function | 16 | $V_{16}$ | – 0.7 to 12 | $V_{pk}$ |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | – | $T_A$ | – 30 to + 70 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 6.0 Vdc, $f_o$ = 10.7 MHz, Δf = ± 3.0 kHz, $f_{mod}$ = 1.0 kHz, 50 Ω source, $T_A$ = 25°C test circuit of Figure 3, unless otherwise noted)

| Characteristics | | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Drain Current (Pins 4 and 8) | Squelch Off<br>Squelch On | –<br>– | 3.6<br>5.4 | 6.0<br>7.0 | mA |
| Input for 20 dB Quieting | | – | 8.0 | – | μVrms |
| Input for – 3.0 dB Limiting | | – | 2.0 | – | μVrms |
| Mixer Voltage Gain (Pin 18 to Pin 3, Open) | | – | 46 | – | |
| Mixer Third Order Intercept, 50 Ω Input | | – | – 1.0 | – | dBm |
| Mixer Input Resistance | | – | 3.6 | – | kΩ |
| Mixer Input Capacitance | | – | 2.2 | – | pF |
| Recovered Audio, Pin 10<br>(Input Signal 1.0 mVrms) | | 450 | 700 | – | mVrms |
| Detector Center Frequency Slope, Pin 10 | | – | 0.3 | – | V/kHz |
| AFC Center Slope, Pin 11, Unloaded | | – | 12 | – | V/kHz |
| Filter Gain (test circuit of Figure 3) | | 40 | 51 | – | dB |
| Squelch Threshold, Through 10K to Pin 14 | | – | 0.62 | – | Vdc |
| Scan Control Current, Pin 15 | Pin 14 – High<br>– Low | –<br>2.0 | 0.01<br>2.4 | 1.0<br>– | μA<br>mA |
| Mute Switch Impedance<br>Pin 16 to Ground | Pin 14 – High<br>– Low | – | 5.0<br>1.5 | 10<br>– | Ω<br>MΩ |

**Figure 3. Test Circuit**

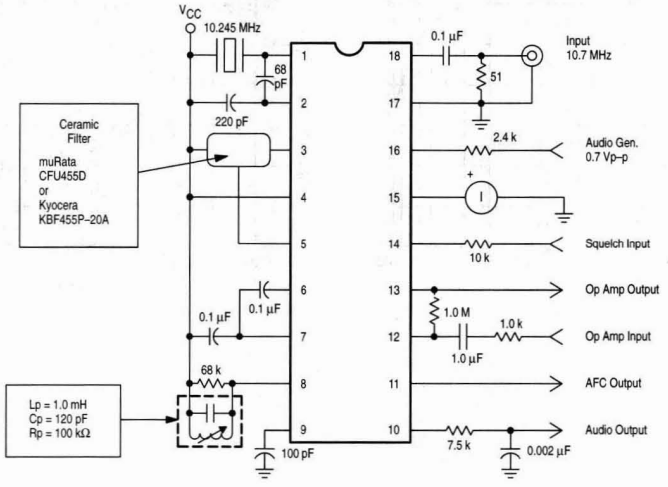


**Figure 4. Mixer Voltage Gain**

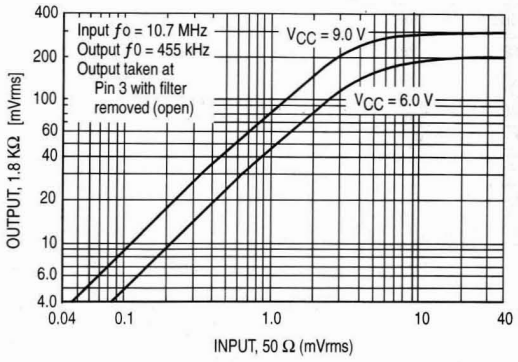



**Figure 5. Limiting IF Frequency Response**

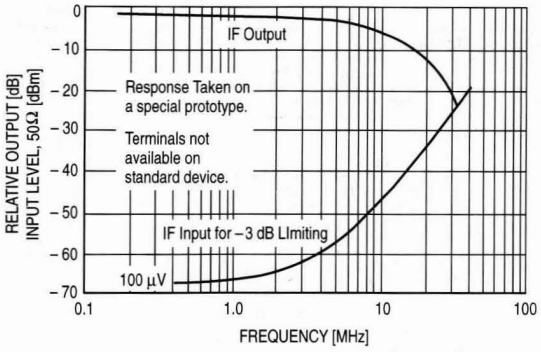



**Figure 6. Mixer Third Order Intermodulation Performance**

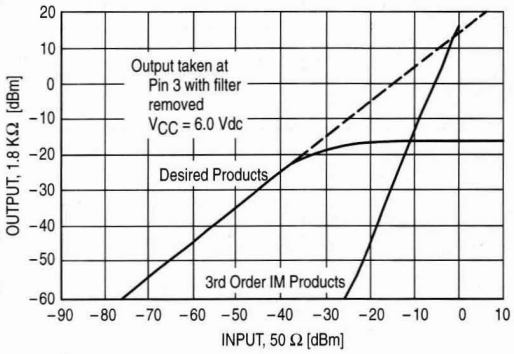



**Figure 7. Detector and AFC Responses**

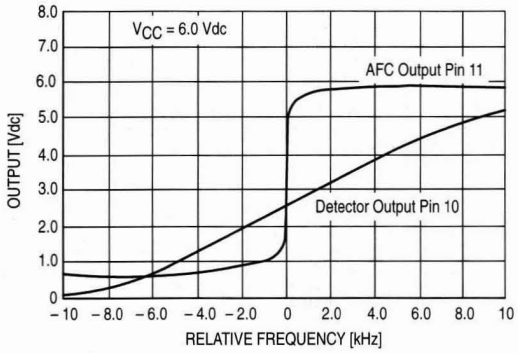



**Figure 8. Relative Mixer Gain**

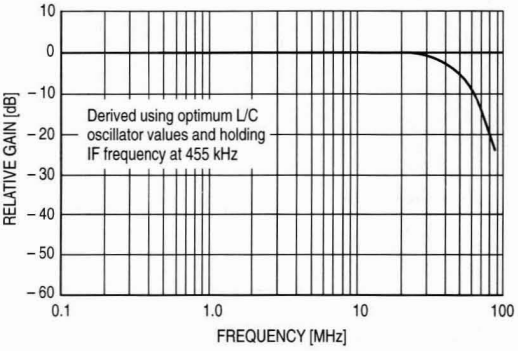



**Figure 9. Overall Gain, Noise, and AM Rejection**

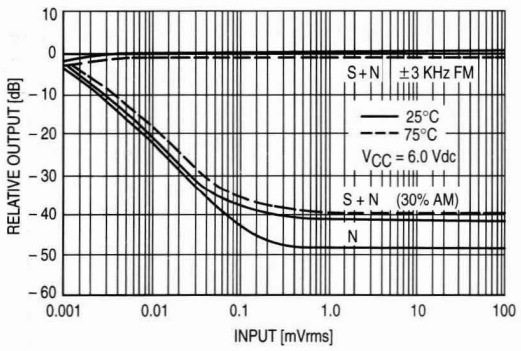



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**Figure 10. Output Components of Signal, Noise, and Distortion**

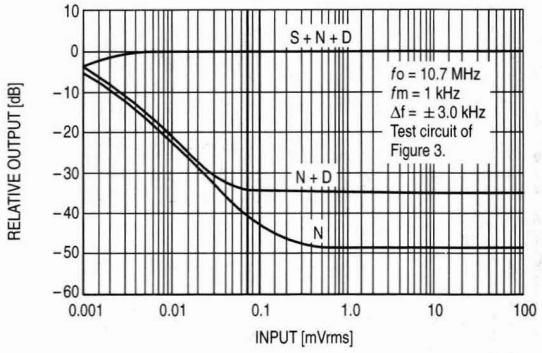


**Figure 11. Audio Output and Total Current Drain versus Supply Voltage**

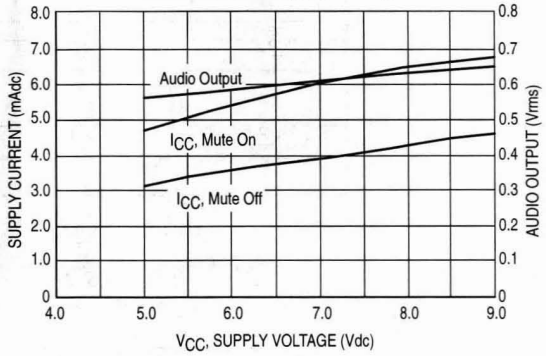


**Figure 12. L/C Oscillator, Temperature and Power Supply Sensitivity**

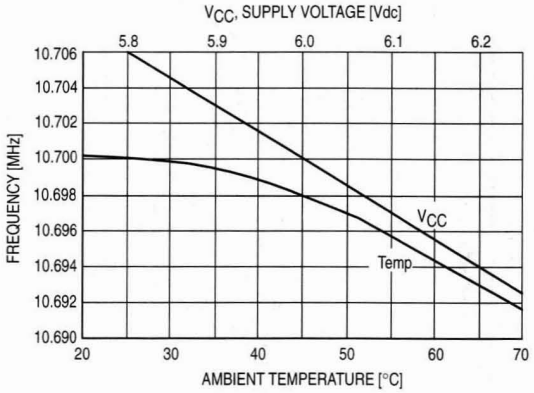


**Figure 13. Op Amp Gain and Phase Response**

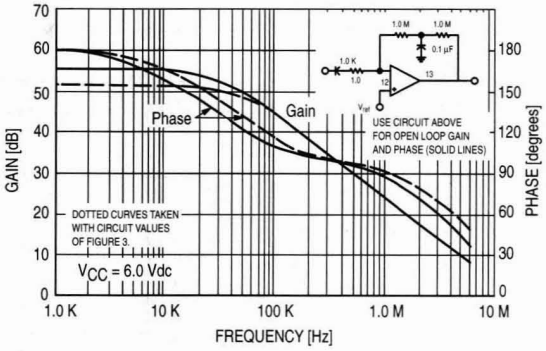
GAIN [dB]
PHASE [degrees]
FREQUENCY [Hz]
Phase
Gain
DOTTED CURVES TAKEN WITH CIRCUIT VALUES OF FIGURE 3.
VCC = 6.0 Vdc
USE CIRCUIT ABOVE FOR OPEN LOOP GAIN AND PHASE (SOLID LINES)

**Figure 14. L/C Oscillator Recommended Component Values**

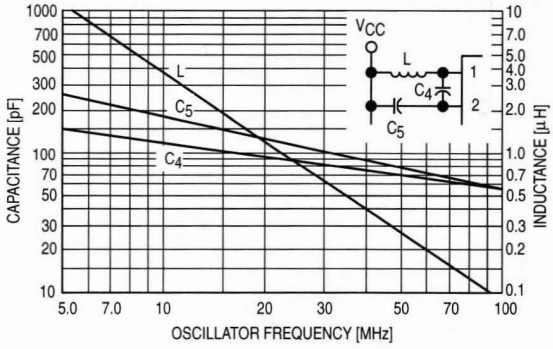


**Figure 15. The Op Amp as a Bandpass Filter**

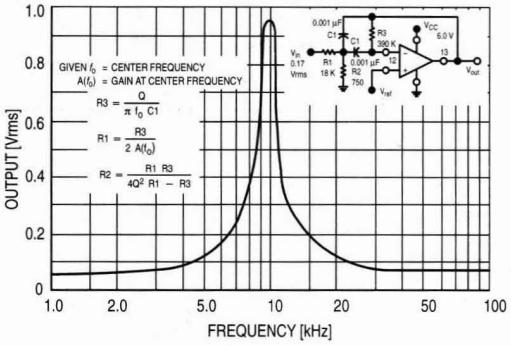


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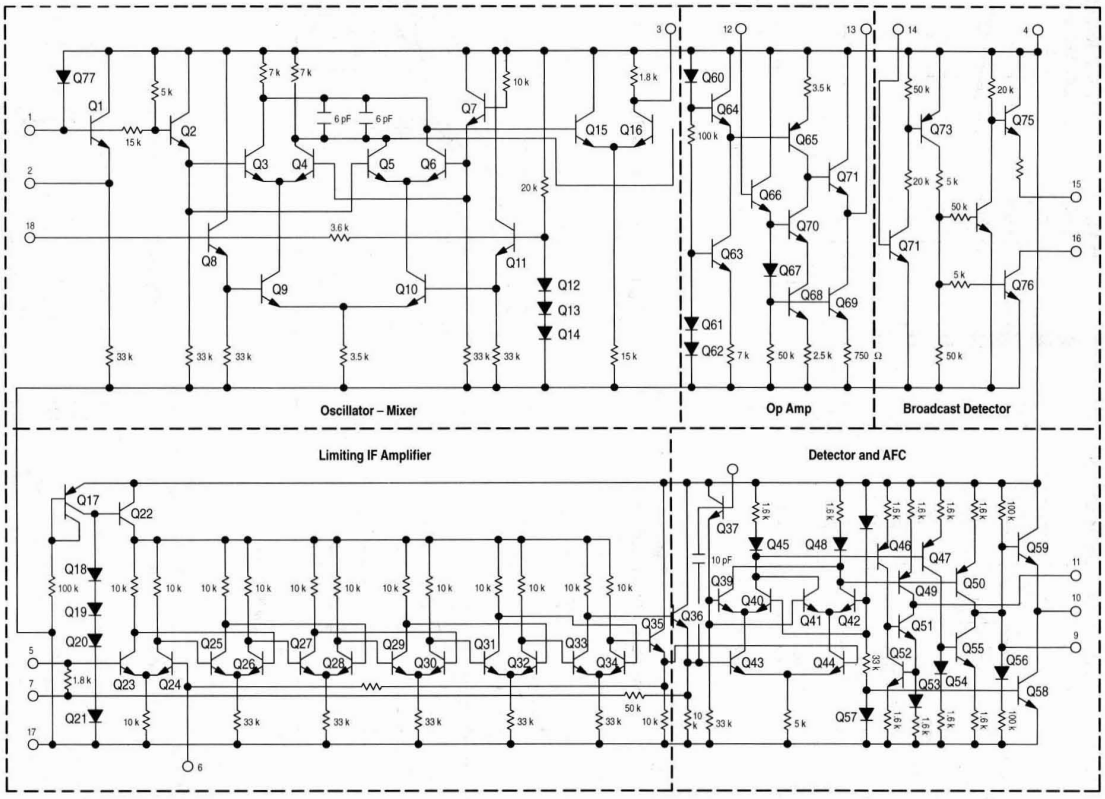
**Figure 16. Representative Schematic Diagram**



## CIRCUIT DESCRIPTION

The MC3359 is a low–power FM IF circuit designed primarily for use in voice–communication scanning receivers. It is also finding a place in narrowband data links.

In the typical application (Figure 1), the mixer–oscillator combination converts the input frequency (10.7 MHz) down to 455 kHz, where, after external bandpass filtering, most of the amplification is done. The audio is recovered using a conventional quadrature FM detector. The absence of an input signal is indicated by the presence of noise above the desired audio frequencies. This "noise band" is monitored by an active filter and a detector. A squelch–trigger circuit indicates the presence of noise (or a tone) by an output which can be used to control scanning. At the same time, an internal switch is operated which can be used to mute the audio.

## APPLICATIONS INFORMATION

The oscillator is an internally biased Colpitts type with the collector, base, and emitter connections at Pin 4, 1 and 2, respectively. The crystal is used in fundamental mode, calibrated for parallel resonance at 32 pF load capacitance. In theory this means that the two capacitors in series should be 32 pF, but in fact much larger values do not significantly affect the oscillator frequency, and provide higher oscillator output.

The oscillator can also be used in the conventional L/C Colpitts configuration without loss of mixer conversion gain. This oscillator is, of course, much more sensitive to voltage and temperature as shown in Figure 12. Guidelines for choosing L and C values are given in Figure 14.

The mixer is doubly balanced to reduce spurious responses. The mixer measurements of Figure 4 and 6 were made using an external 50 Ω source and the internal 1.8 k at Pin 3. Voltage gain curves at several $V_{CC}$ voltages are shown in Figure 4. The Third Order Intercept curves of Figure 6 are shown using the conventional dBm scales. Measured power gain (with the 50 Ω input) is approximately 18 dB but the useful gain is much higher because the mixer input impedance is over 3 kΩ. Most applications will use a 330 Ω 10.7 MHz crystal filter ahead of the mixer. For higher frequencies, the relative mixer gain is given in Figure 8.

Following the mixer, a ceramic bandpass filter is recommended. The 455 kHz types come in bandwidths from ± 2 kHz to ± 15 kHz and have input and output impedances of 1.5 k to 2.0 k. For this reason, the Pin 5 input to the 6 stage limiting IF has an internal 1.8 k resistor. The IF has a 3 dB limiting sensitivity of approximately 100 μV at Pin 5 and a useful frequency range of about 5 MHz as shown in Figure 5. The frequency limitation is due to the high resistance values in the IF, which were necessary to meet the low power requirement. The output of the limiter is internally connected to the quadrature detector, including the 10 pF quadrature capacitor. Only a parallel L/C is needed externally from Pin 8 to $V_{CC}$. A shunt resistance can be added to widen the peak separation of the quadrature detector.

The detector output is amplified and buffered to the audio output, Pin 10, which has an output impedance of approximately 300 Ω. Pin 9 provides a high impedance (50 k) point in the output amplifier for application of a filter or de–emphasis capacitor. Pin 11 is the AFC output, with high gain and high output impedance (1 M). If not needed, it should be grounded, or it can be connected to Pin 9 to double the recovered audio. The detector and AFC responses are shown in Figure 7.

Overall performance of the MC3359 from mixer input to audio output is shown in Figure 9 and 10. The MC3359 can also be operated in "single conversion" equipment; i.e., the mixer can be used as a 455 kHz amplifier. The oscillator is disabled by connecting Pin 1 to Pin 2. In this mode, the overall performance is identical to the 10.7 MHz results of Figure 9.

A simple inverting op amp is provided with an output at Pin 13 providing dc bias (externally) to the input at Pin 12, which is referred internally to 2.0 V. A filter can be made with external impedance elements to discriminate between frequencies. With an external AM detector, the filtered audio signal can be checked for the presence of either noise above the normal audio, or a tone signal.

The open loop response of this op amp is given in Figure13. Bandpass filter design information is provided in Figure 15.

A low bias to Pin 14 sets up the squelch–trigger circuit so that Pin 15 is high, a source of at least 2.0 mA, and the audio mute (Pin 16) is open–circuit. If Pin 14 is raised to 0.7 V by the noise or tone detector, Pin 15 becomes open circuit and Pin 16 is internally short circuited to ground. There is no hysteresis. Audio muting is accomplished by connecting Pin 16 to a high–impedance ground–reference point in the audio path between Pin 10 and the audio amplifier. No dc voltage is needed, in fact it is not desirable because audio "thump" would result during the muting function. Signal swing greater than 0.7 V below ground on Pin 16 should be avoided.

MOTOROLA

# Low-Power Narrowband FM Receiver

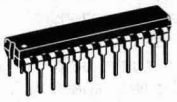
. . . includes dual FM conversion with oscillators, mixers, quadrature discriminator, and meter drive/carrier detect circuitry. The MC3362 also has buffered first and second local oscillator outputs and a comparator circuit for FSK detection.

- Complete Dual Conversion Circuitry
- Low Voltage: $V_{CC}$ = 2.0 to 6.0 Vdc
- Low Drain Current (3.6 mA (Typical) @ $V_{CC}$ = 3.0 Vdc)
- Excellent Sensitivity: Input Voltage 0.6 μVrms (Typical) for 12 dB SINAD
- Externally Adjustable Carrier Detect Function
- Low Number of External Parts Required
- Manufactured Using Motorola's MOSAIC® Process Technology
- MC13135 is Preferred for New Designs

**MC3362**

**LOW–POWER DUAL CONVERSION FM RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 724

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
(SO-24L)

8

**Figure 1. Simplified Application in a PLL Frequency Synthesized Receiver**

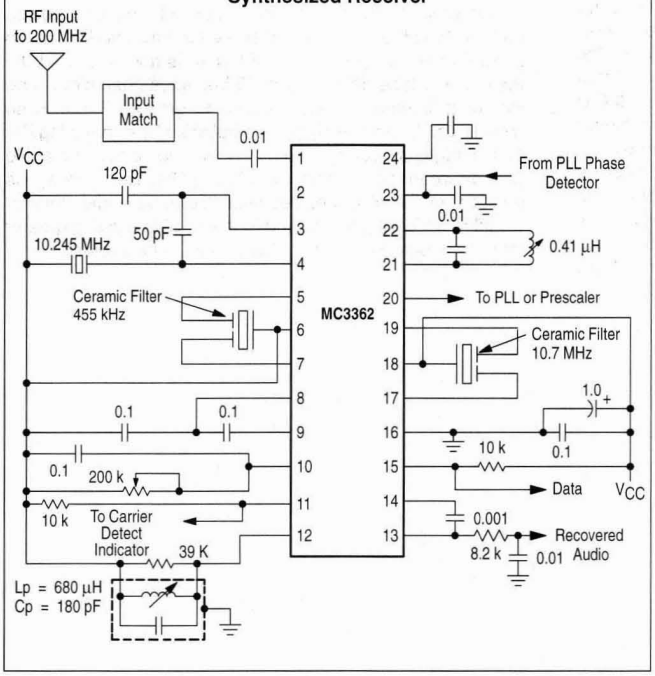
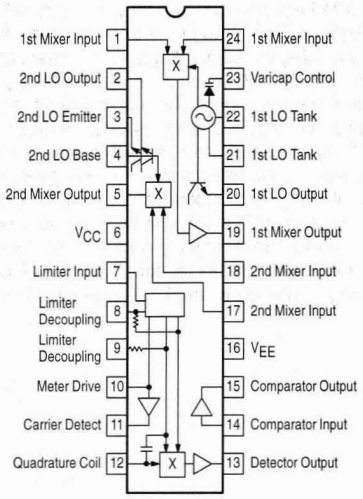



**Figure 2. Pin Connections and Representative Block Diagram**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3362DW | $T_A$ = – 40 to +85°C | SO–24L |
| MC3362P | | Plastic DIP |

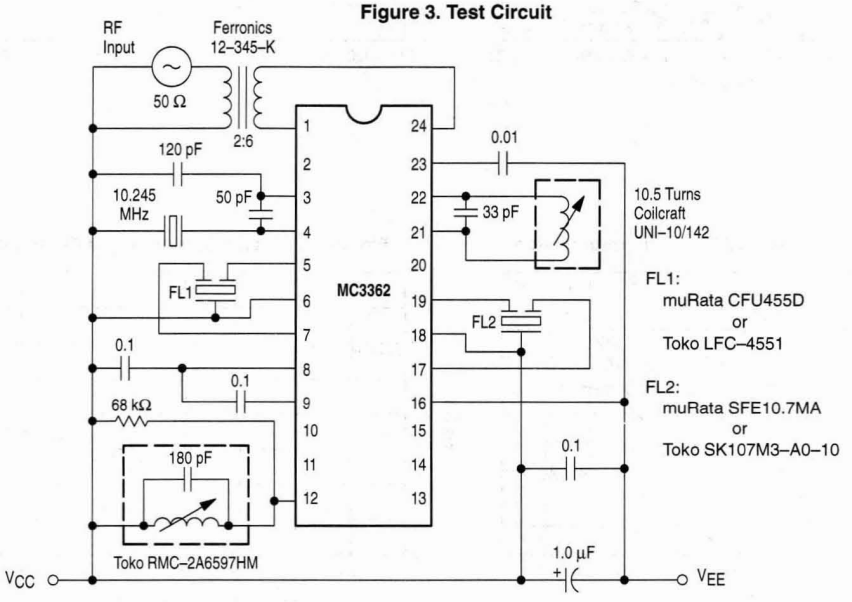
**MAXIMUM RATING** ($T_A$ = 25°C, unless otherwise noted)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage (See Figure 2) | 6 | $V_{CC(max)}$ | 7.0 | Vdc |
| Operating Supply Voltage Range (Recommended) | 6 | $V_{CC}$ | 2.0 to 6.0 | Vdc |
| Input Voltage ($V_{CC}$ ≥ 5.0 Vdc) | 1, 24 | $V_{1-24}$ | 1.0 | Vrms |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | – | $T_A$ | – 40 to + 85 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to + 150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $f_o$ = 49.7 MHz, Deviation = 3.0 kHz, $T_A$ = 25°C, Test Circuit of Figure 3, unless otherwise noted)

| Characteristic | Pin | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Drain Current (Carrier Detect Low – See Figure 5) | 6 | – | 4.5 | 7.0 | mA |
| Input for –3.0 dB Limiting | | – | 0.7 | 2.0 | µVrms |
| Input for 12 dB SINAD (See Figure 9) | | – | 0.6 | – | µVrms |
| Series Equivalent Input Impedence | | – | 450–j350 | – | Ω |
| Recovered Audio (RF signal level = 10 mV) | 13 | – | 350 | – | mVrms |
| Noise Output (RF signal level = 0 mV) | 13 | – | 250 | – | mVrms |
| Carrier Detect Threshold (below $V_{CC}$) | 10 | – | 0.64 | – | Vdc |
| Meter Drive Slope | 10 | – | 100 | – | nA/dB |
| Input for 20 dB (S + N)/N (See Figure 7) | | – | 0.7 | – | µVrms |
| First Mixer 3rd Order Intercept (Input) | | – | –22 | – | dBm |
| First Mixer Input Resistance (Rp) | | – | 690 | – | Ω |
| First Mixer Input Capacitance (Cp) | | – | 7.2 | – | pF |
| Conversion Voltage Gain, First Mixer | | – | 18 | – | dB |
| Conversion Voltage Gain, Second Mixer | | – | 21 | – | |
| Dector Output Resistance | 13 | – | 1.4 | – | kΩ |

**Figure 3. Test Circuit**




**NOTE:** See AN980 for Additional Design Information.

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**Figure 4. $I_{Meter}$ versus Input**

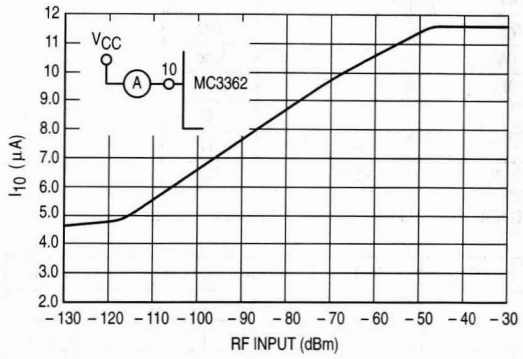


**Figure 5. Drain Current, Recovered Audio versus Supply**

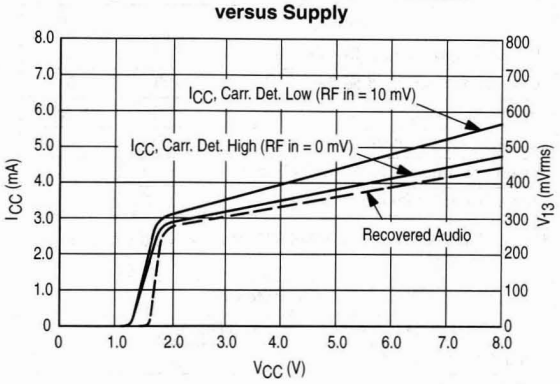


**Figure 6. Signal Levels**

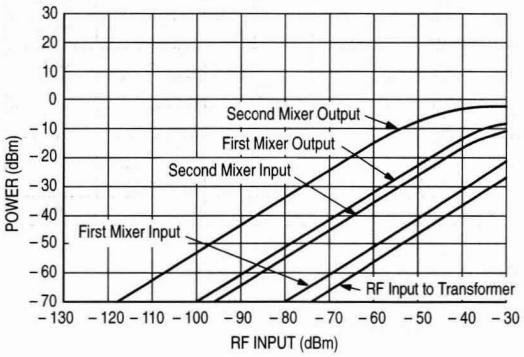


**Figure 7. S + N, N, AMR versus Input**

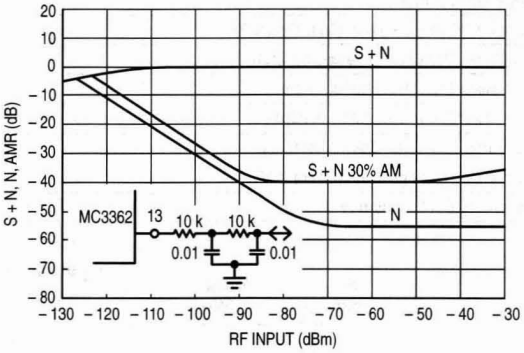


**Figure 8. 1st Mixer 3rd Order Intermodulation**

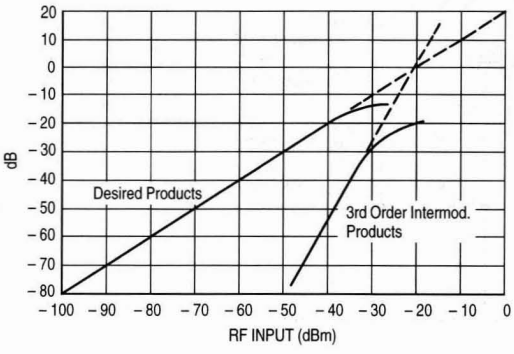


**Figure 9. Detector Output versus Frequency**

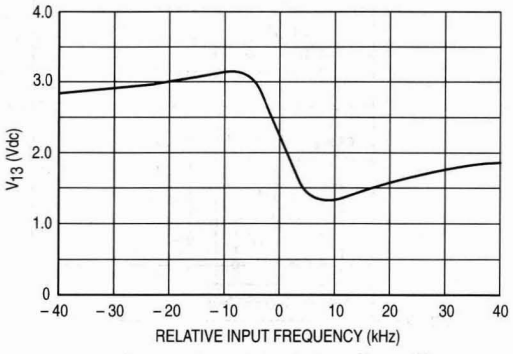


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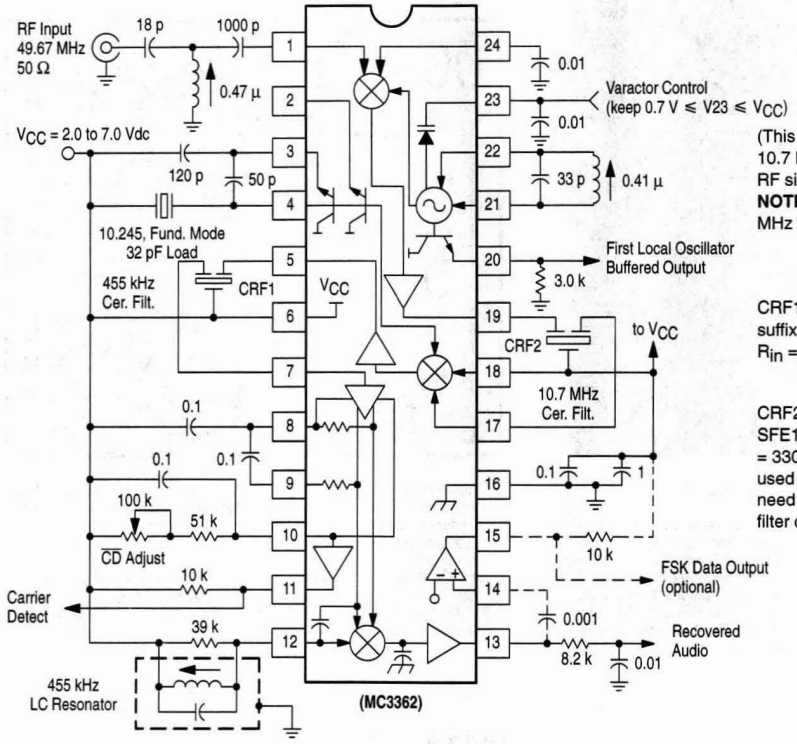
**Figure 10. PC Board Test Circuit**
(LC Oscillator Configuration Used in PLL Synthesized Receiver)

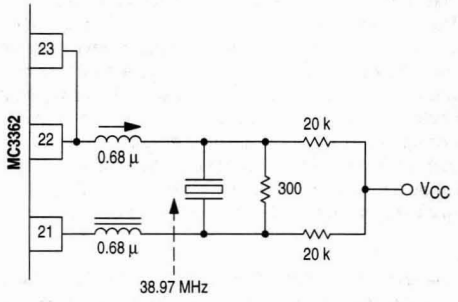



(This network must be tuned to exactly 10.7 MHz above or below the incoming RF signal.
**NOTE:** The IF is rolled off above 10.7 MHz to reduce L.O. feedthrough.)

CRF1 = muRata CFU 455X – the X suffix denotes 6.0 dB bandwidth. $R_{in} = R_{out} = 1.5$ to 2.0 kΩ.

CRF2 = muRata SFA10.7 MF5 or SFE10.7 or equivalent. $R_{in} = R_{out} = 330\ \Omega$. Crystal filters can be used but impedance matching will need to be added to ensure proper filter characteristics are realized.

**Figure 10A. Crystal Oscillator Configuration for Single Channel Application**




Crystal used is series mode resonant (no load capacity specified), 3rd overtone. This method has not proven adequate for fundamental mode, 5th or 7th overtone crystals. The inductor and capacitor will need to be changed for other frequency crystals. See AN980 for further information.

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**Figure 11. Component Placement View Showing Crystal Oscillator Circuit**

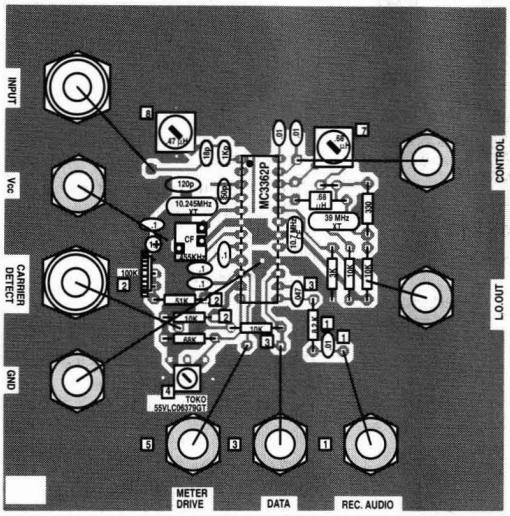
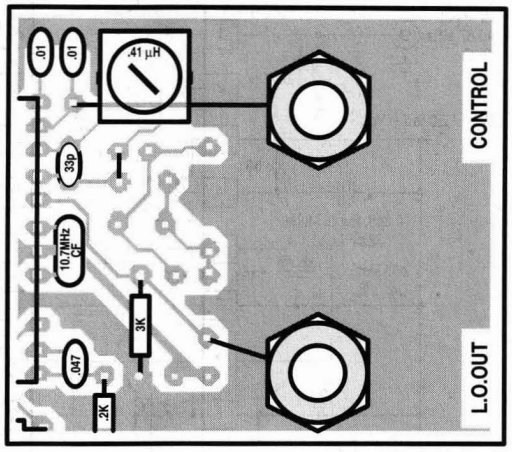



**Figure 11A. LC Oscillator Component View**




**NOTES:** 1. Recovered Audio components may be deleted when using data output.
2. Carrier Detect components must be deleted in order to obtain linear Meter Drive output. With these components in place the Meter Drive outputs serve only to trip the Carrier Detect indicator.
3. Data Output components should be deleted in applications where only audio modulation is used. For combined audio/data applications, the 0.047 µF coupling capacitor will add distortion to the audio, so a pull–down resistor at pin 13 may be required.
4. Use Toko 7MC81282 Quadrature coil.
5. Meter Drive cannot be used simultaneously with Carrier Detect output. For analog meter drive, remove components labelled "2" and measure meter current (4–12 µA) through ammeter to $V_{CC}$.
6. Either type of oscillator circuit may be used with any output circuit configuration.
7. LC Oscillator Coil: Coilcraft UNI 10/42 10.5 turns, 0.41 µH Crystal Oscillator circuit: trim coil, 0.68 µH. Coilcraft M1287–A.
8. 0.47 H, Coilcraft M1286–A. Input LC network used to match first mixer input impedance to 50 Ω.

8

## CIRCUIT DESCRIPTION

The MC3362 is a complete FM narrowband receiver from antenna input to audio preamp output. The low voltage dual conversion design yields low power drain, excellent sensitivity and good image rejection in narrowband voice and data link applications.

In the typical application (Figure 1), the first mixer amplifies the signal and converts the RF input to 10.7 MHz. This IF signal is filtered externally and fed into the second mixer, which further amplifies the signal and converts it to a 455 kHz IF signal. After external bandpass filtering, the low IF is fed into the limiting amplifier and detection circuitry. The audio is recovered using a conventional quadrature detector. Twice–IF filtering is provided internally.

The input signal level is monitored by meter drive circuitry which detects the amount of limiting in the limiting amplifier. The voltage at the meter drive pin determines the state of the carrier detect output, which is active low.

## APPLICATIONS INFORMATION

The first local oscillator can be run using a free–running LC tank, as a VCO using PLL synthesis, or driven from an external crystal oscillator. It has been run to 190 MHz.* A buffered output is available at Pin 20. The second local oscillator is a common base Colpitts type which is typically run at 10.245 MHz under crystal control. A buffered output is available at Pin 2. Pins 2 and 3 are interchangeable.

The mixers are doubly balanced to reduce spurious responses. The first and second mixers have conversion gains of 18 dB and 22 dB (typical), respectively, as seen in Figure 6. Mixer gain is stable with respect to supply voltage. For both conversions, the mixer impedances and pin layout are designed to allow the user to employ low cost, readily available ceramic filters. Overall sensitivity and AM rejection are shown in Figure 7. The input level for 20 dB (S + N)/N is 0.7 µV using the two–pole post–detection filter pictured.

* If the first local oscillator (Pins 21 and/or 22) is driven from a strong external source (100 mVrms), the mixer can be used to over 450 MHz.

Following the first mixer, a 10.7 MHz ceramic band–pass filter is recommended. The 10.7 MHz filtered signal is then fed into one second mixer input pin, the other input pin being connected to $V_{CC}$. Pin 6 ($V_{CC}$) is treated as a common point for emitter–driven signals.

The 455 kHz IF is typically filtered using a ceramic bandpass filter then fed into the limiter input pin. The limiter has 10 μV sensitivity for – 3.0 dB limiting, flat to 1.0 MHz.

The output of the limiter is internally connected to the quadrature detector, including a quadrature capacitor. A parallel LC tank is needed externally from Pin 12 to $V_{CC}$. A 39 kΩ shunt resistance is included which determines the peak separation of the quadrature detector; a smaller value will increase the spacing and linearity but decrease recovered audio and sensitivity.

A data shaping circuit is available and can be coupled to the recovered audio output of Pin 13. The circuit is a comparator which is designed to detect zero crossings of FSK modulation. Data rates are typically limited to 1200 baud to ensure data integrity and avoid adjacent channel "splatter." Hysteresis is available by connecting a high valued resistor from Pin 15 to Pin 14. Values below 120 kΩ are not recommended as the input signal cannot overcome the hysteresis.

The meter drive circuitry detects input signal level by monitoring the limiting amplifier stages. Figure 4 shows the unloaded current at Pin 10 versus input power. The meter drive current can be used directly (RSSI) or can be used to trip the carrier detect circuit at a specified input power. To do this, pick an RF trip level in dBm. Read the corresponding current from Figure 4 and pick a resistor such that:

$$R_{10} \simeq 0.64\ \text{Vdc} / I_{10}$$

Hysteresis is available by connecting a high valued resistor $R_H$ between Pins 10 and 11. The formula is:

$$\text{Hysteresis} = V_{CC}/(R_H \times 10^{-7})\ \text{dB}$$

**Figure 12. Circuit Side View**

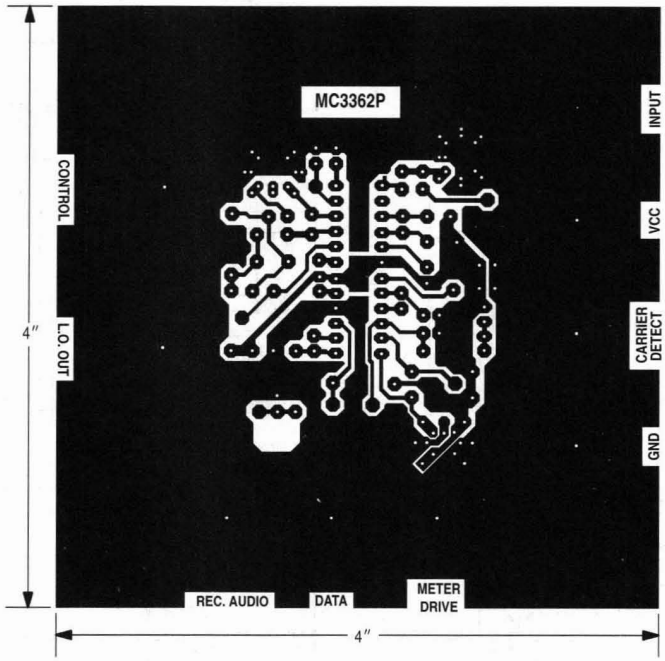



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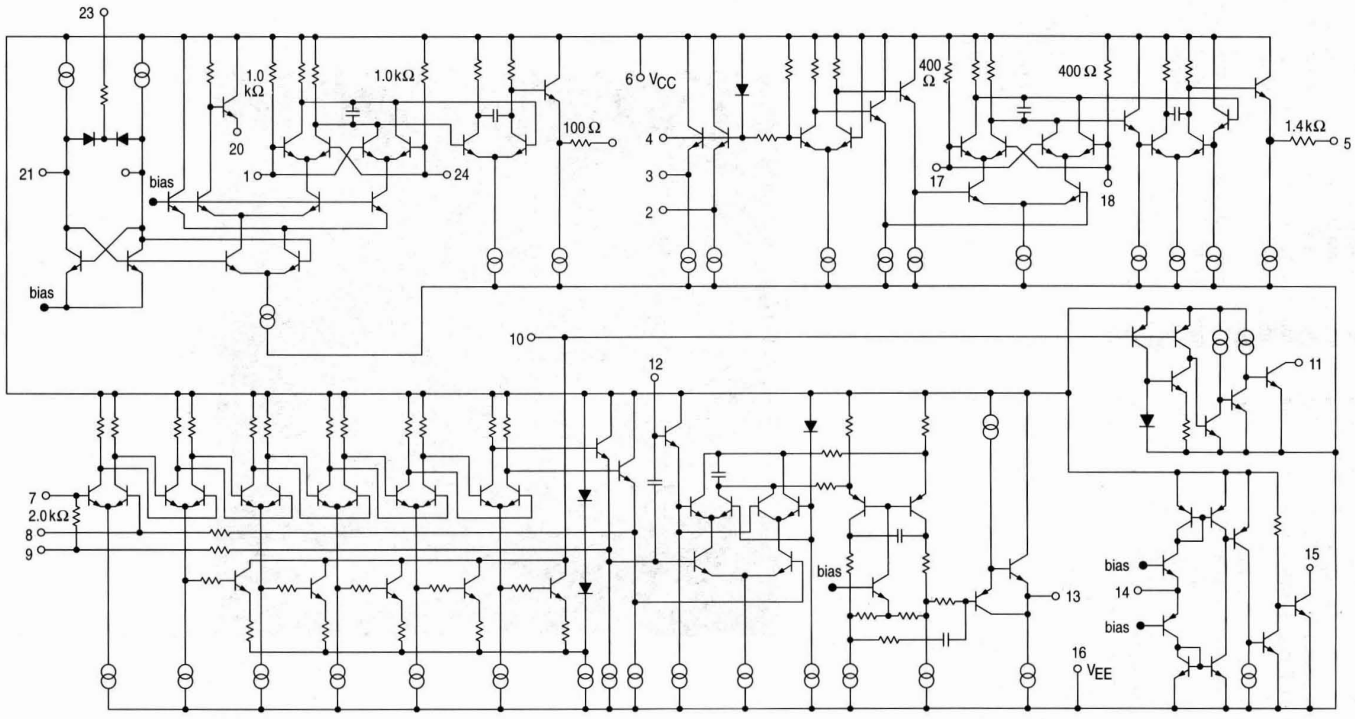
**Figure 13. Representative Schematic Diagram**



MOTOROLA

# MC3363

# Low Power Dual Conversion FM Receiver

The MC3363 is a single chip narrowband VHF FM radio receiver. It is a dual conversion receiver with RF amplifier transistor, oscillators, mixers, quadrature detector, meter drive/carrier detect and mute circuitry. The MC3363 also has a buffered first local oscillator output for use with frequency synthesizers, and a data slicing comparator for FSK detection.

- Wide Input Bandwidth – 200 MHz Using Internal Local Oscillator
  – 450 MHz Using External Local Oscillator
- RF Amplifier Transistor
- Muting Operational Amplifier
- Complete Dual Conversion
- Low Voltage: $V_{CC}$ = 2.0 V to 6.0 Vdc
- Low Drain Current: $I_{CC}$ = 3.6 mA (Typical) at $V_{CC}$ = 3.0 V, Excluding RF Amplifier Transistor
- Excellent Sensitivity: Input 0.3 μV (Typical) for 12 dB SINAD Using Internal RF Amplifier Transistor
- Data Shaping Comparator
- Received Signal Strength Indicator (RSSI) with 60 dB Dynamic Range
- Low Number of External Parts Required
- Manufactured in Motorola's MOSAIC® Process Technology

**LOW POWER DUAL CONVERSION FM RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F
(SO-28L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3363DW | $T_A$ = – 40 to +85°C | SO–28L |

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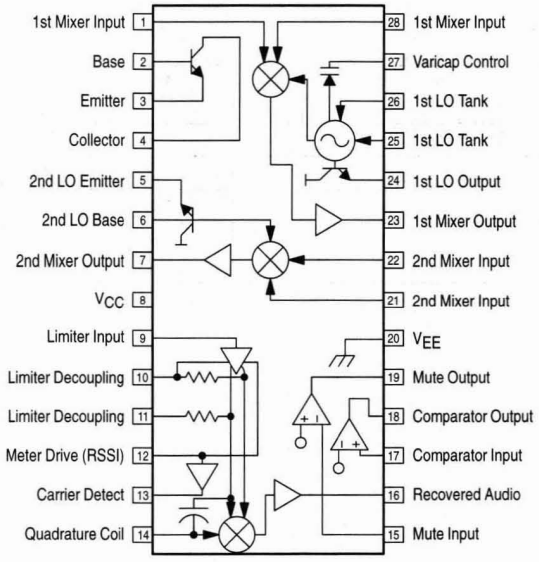
**Figure 1. Pin Connections and Representative Block Diagram**



**MAXIMUM RATINGS** ($T_A$ = 25°C unless otherwise noted)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 8 | $V_{CC(max)}$ | 7.0 | Vdc |
| Operating Supply Voltage Range (Recommended) | 8 | $V_{CC}$ | 2.0 to 6.0 | Vdc |
| Input Voltage ($V_{CC}$ = 5.0 Vdc) | 1, 28 | $V_{1-28}$ | 1.0 | Vrms |
| Mute Output Voltage | 19 | $V_{19}$ | – 0.7 to 8.0 | Vpk |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | – | $T_A$ | – 40 to +85 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $f_o$ = 49.7 MHz, Deviation = ±3.0 kHz, $T_A$ = 25°C, Mod 1.0 kHz, test circuit of Figure 2 unless otherwise noted)

| Characteristic | Pin | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Drain Current (Carrier Detect Low) | 8 | – | 4.5 | 8.0 | mA |
| –3.0 dB Limiting Sensitivity (RF Amplifier Not Used) | | – | 0.7 | 2.0 | µVrms |
| Input For 12 dB SINAD | | – | 0.3 | – | |
| 20 dB S/N Sensitivity (RF Amplifier Not Used) | | – | 1.0 | – | |
| 1st Mixer Input Resistance (Parallel – Rp) | 1, 28 | – | 690 | – | Ω |
| 1st Mixer Input Capacitance (Parallel – Cp) | 1, 28 | – | 7.2 | – | pF |
| 1st Mixer Conversion Voltage Gain ($A_{vc1}$, Open Circuit) | | – | 18 | – | dB |
| 2nd Mixer Conversion Voltage Gain )$A_{vc2}$, Open Circuit) | | – | 21 | – | |
| 2nd Mixer Input Sensitivity (20 dB S/N) (10.7 MHz i/p) | 21 | – | 10 | – | µVrms |
| Limiter Input Sensitivity (20 dB S/N) (455 kHz i/p) | 9 | – | 100 | – | |
| RF Transistor DC Current Drain | 4 | 1.0 | 1.5 | 2.5 | mAdc |
| Noise Output Level (RF Signal = 0 mV) | 16 | – | 70 | – | mVrms |
| Recovered Audio (RF Signal Level = 1.0 mV) | 16 | 120 | 200 | – | mVrms |
| THD of Recovered Aduio (RF Signal = 1.0 mV) | 16 | – | 2% | – | % |
| Detector Output Impedance | 16 | – | 400 | – | Ω |
| Series Equivalent Input Impedance | 1 | – | 450–<br>j350 | – | |
| Data (Comparator) Output Voltage – High<br>– Low | 18 | –<br>0.1 | –<br>0.1 | $V_{CC}$<br>– | Vdc |
| Data (Comparator) Threshold Voltage Difference | 17 | 70 | 110 | 150 | mV |
| Meter Drive Slope | 12 | 70 | 100 | 135 | nA/dB |
| Carrier Detect Threshold (Below $V_{CC}$) | 12 | 0.53 | 0.64 | 0.77 | Vdc |
| Mute Output Impedance – High<br>– Low | 19 | –<br>– | 10<br>25 | –<br>– | MΩ |

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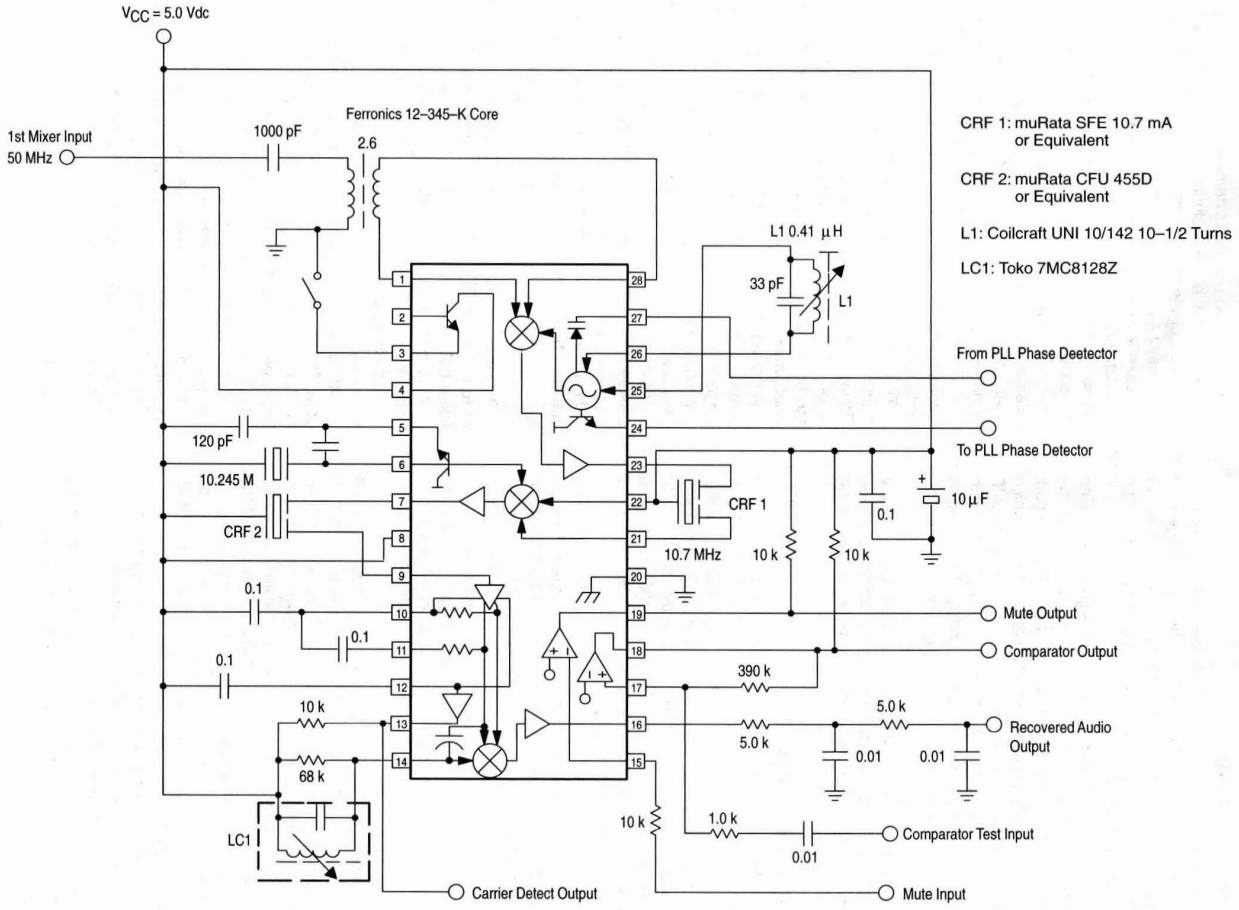
**Figure 2. Test Circuit**



## CIRCUIT DESCRIPTION

The MC3363 is a complete FM narrowband receiver from RF amplifier to audio preamp output. The low voltage dual conversion design yields low power drain, excellent sensitivity and good image rejection in narrowband voice and data link applications.

In the typical application, the input RF signal is amplified by the RF transistor and then the first mixer amplifies the signal and converts the RF input to 10.7 MHz. This IF signal is filtered externally and fed into the second mixer, which further amplifies the signal and converts it to a 455 kHz IF signal. After external bandpass filtering, the low IF is fed into the limiting amplifier and detection circuitry. The audio is recovered using a conventional quadrature detector. Twice-IF filtering is provided internally.

The input signal level is monitored by meter drive circuitry which detects the amount of limiting in the limiting amplifier. The voltage at the meter drive pin determines the state of the carrier detect output, which is active low.

## APPLICATIONS INFORMATION

The first local oscillator is designed to serve as the VCO in a PLL frequency synthesized receiver. The MC3363 can operate together with the MC145166/7 to provide a two-chip ten–channel frequency synthesized receiver in the 46/49 cordless telephone band. The MC3363 can also be used with the MC14515X series of CMOS PLL synthesizers and MC120XX series of ECL prescalers in VHF frequency synthesized applications to 200 MHz.

For single channel applications the first local oscillator can be crystal controlled. The circuit of Figure 4 has been used successfully up to 60 MHz. For higher frequencies an external oscillator signal can be injected into Pins 25 and/or 26 — a level of approximately 100 mVrms is recommended. The first mixer's transfer characteristic is essentially flat to 450 MHz when this approach is used (keeping a constant 10.7 MHz IF frequency). The second local oscillator is a Colpitts type which is typically run at 10.245 MHz under crystal control.

The mixers are doubly balanced to reduce spurious responses. The first and second mixers have conversion gains of 18 dB and 21 dB (typical), respectively. Mixer gain is stable with respect to supply voltage. For both conversions, the mixer impedances and pin layout are designed to allow the user to employ low cost, readily available ceramic filters.

Following the first mixer, a 10.7 MHz ceramic bandpass filter is recommended. The 10.7 MHz filtered signal is then fed into the second mixer input Pin 21, the other input Pin 22 being connected to $V_{CC}$.

The 455 kHz IF is filtered by a ceramic narrow bandpass filter then fed into the limiter input Pin 9. The limiter has 10 μV sensitivity for −3.0 dB limiting, flat to 1.0 MHz.

The output of the limiter is internally connected to the quadrature detector, including a quadrature capacitor. A parallel LC tank is needed externally from Pin 14 to $V_{CC}$. A 68 kΩ shunt resistance is included which determines the peak separation of the quadrature detector; a smaller value will lower the Q and expand the deviation range and linearity, but decrease recovered audio and sensitivity.

A data shaping circuit is available and can be coupled to the recovered audio output of Pin 16. The circuit is a comparator which is designed to detect zero crossings of FSK modulation. Data rates of up to 35000 baud are detectable using the comparator. Best sensitivity is obtained when data rates are limited to 1200 baud maximum. Hysteresis is available by connecting a high-valued resistor from Pin 17 to Pin 18. Values below 120 kΩ are not recommended as the input signal cannot overcome the hysteresis.

The meter drive circuitry detects input signal level by monitoring the limiting of the limiting amplifier stages. Figure 5 shows the unloaded current at Pin 12 versus input power. The meter drive current can used directly (RSSI) or can be used to trip the carrier detect circuit at a specified input power.

A muting op amp is provided and can be triggered by the carrier detect output (Pin 13). This provides a carrier level triggered squelch circuit which is activated when the RF input at the desired input frequency falls below a present level. The level at which this occurs is determined by the resistor placed between the meter drive output (Pin 12) and $V_{CC}$. Values between 80–130 kΩ are recommended. This type of squelch is pictured in Figures 3 and 4.

Hysteresis is available by connecting a high-valued resistor Rh between Pins 12 and 13. The formula is:

$$\text{Hyst} = V_{CC} / (\text{Rh} \times 10^{-7}) \text{ dB}$$

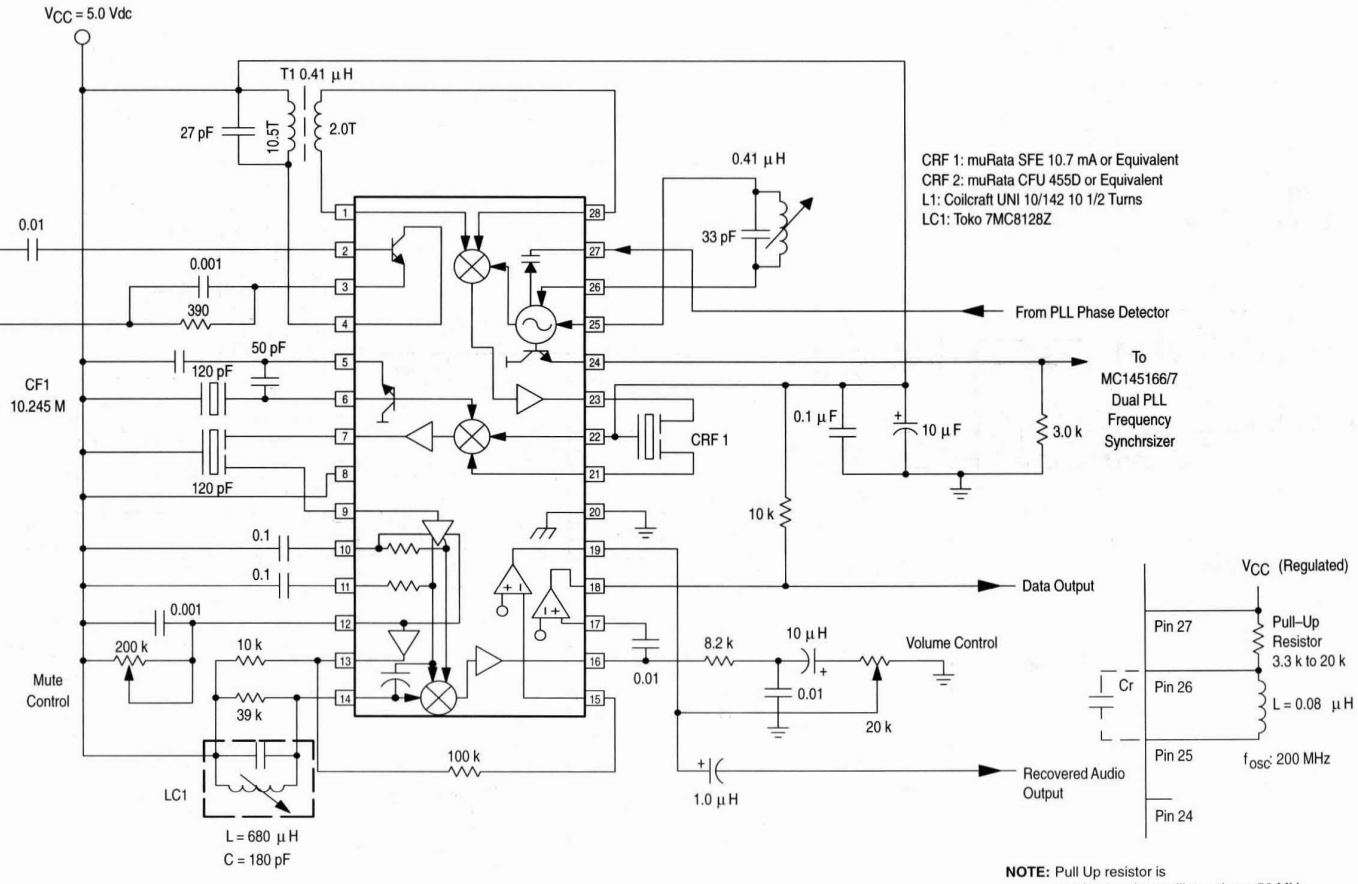
The meter drive can also be used directly to drive a meter or to provide AGC. A current to voltage converter or other linear buffer will be needed for this application.

A second possible application of the op amp would be in a noise triggered squelch circuit, similar to that used with the MC3357/MC3359/MC3361B FM IFs. In this case the op amp would serve as an active noise filter, the output of which would be rectified and compared to a reference on a squelch gate. The MC3363 does not have a dedicated squelch gate, but the NPN RF input stage or data shaping comparator might be used to provide this function if available. The op amp is a basic type with the inverting input and the output available. This application frees the meter drive to allow it to be used as a linear signal strength monitor.

The circuit of Figure 4 is a complete 50 MHz receiver from antenna input to audio preamp output. It uses few components and has good performance. The receiver operates on a single channel and has input sensitivity of < 0.3 μV for 12 dB SINAD.

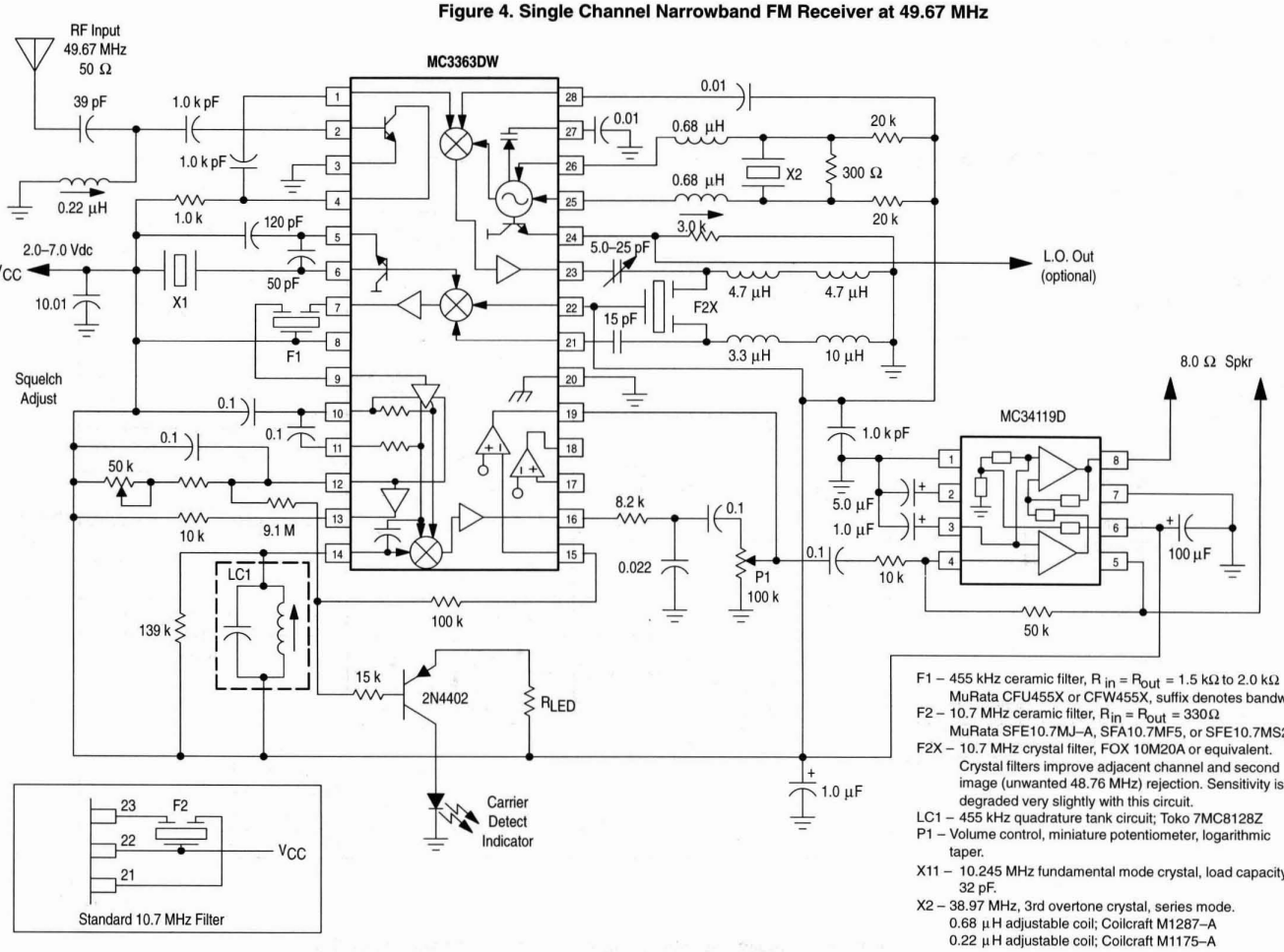
**NOTE:** For further application and design information, refer to AN980.

**Figure 3. Typical Application in a PLL Frequency Synthesized Receiver**




**NOTE:** Pull Up resistor is used to run the oscillator above 50 MHz.

**Figure 4. Single Channel Narrowband FM Receiver at 49.67 MHz**




F1 – 455 kHz ceramic filter, $R_{in} = R_{out}$ = 1.5 kΩ to 2.0 kΩ
MuRata CFU455X or CFW455X, suffix denotes bandwidth
F2 – 10.7 MHz ceramic filter, $R_{in} = R_{out}$ = 330Ω
MuRata SFE10.7MJ–A, SFA10.7MF5, or SFE10.7MS2A.
F2X – 10.7 MHz crystal filter, FOX 10M20A or equivalent.
Crystal filters improve adjacent channel and second image (unwanted 48.76 MHz) rejection. Sensitivity is degraded very slightly with this circuit.
LC1 – 455 kHz quadrature tank circuit; Toko 7MC8128Z
P1 – Volume control, miniature potentiometer, logarithmic taper.
X11 – 10.245 MHz fundamental mode crystal, load capacity 32 pF.
X2 – 38.97 MHz, 3rd overtone crystal, series mode.
0.68 µH adjustable coil; Coilcraft M1287–A
0.22 µH adjustable coil; Coilcraft M1175–A

$R_{LED}$ is used to adjust LED current: $I_{LED} \approx \frac{V_{CC} - V_{LED}}{R_{LED}}$

**Figure 5. Circuit Schematic**

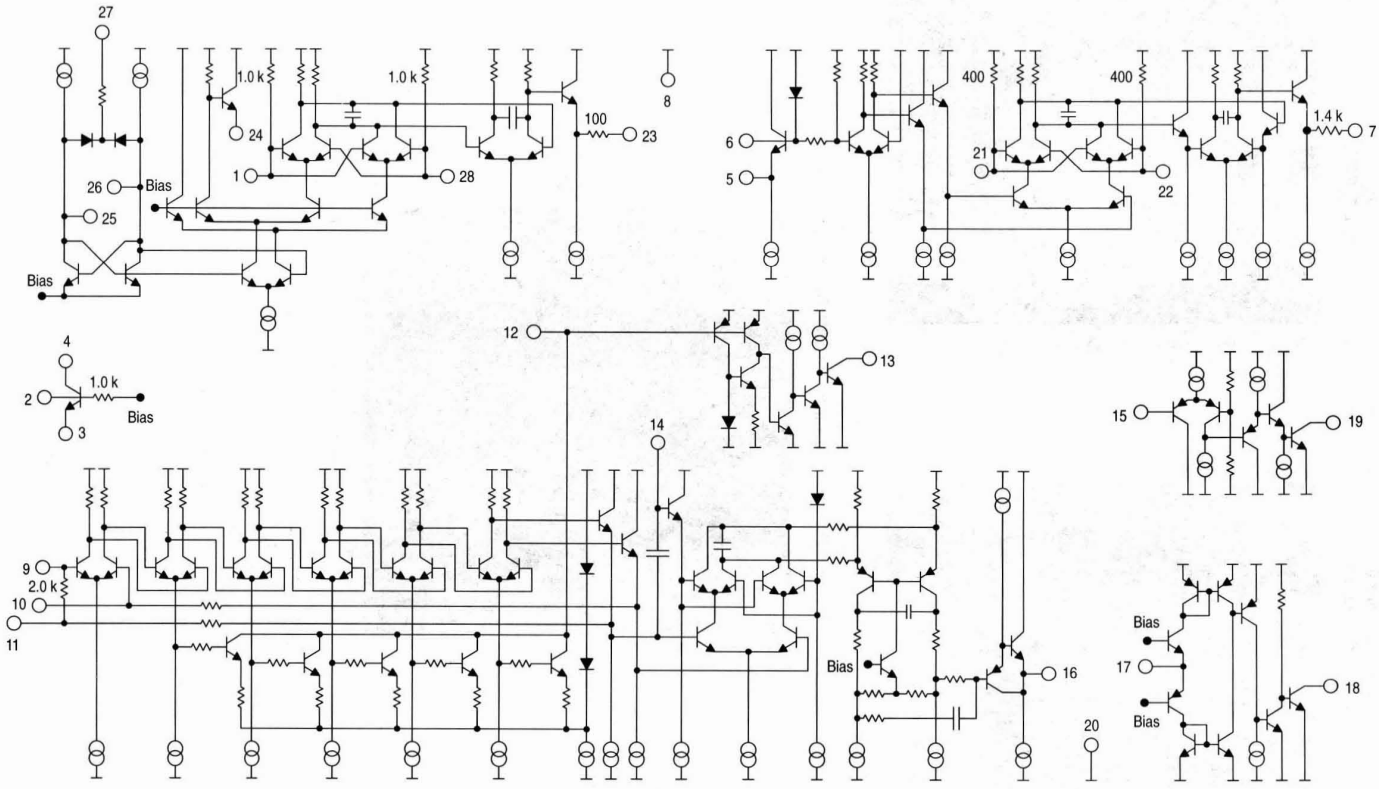


Figure 6. PC Board Component View with High Performance Crystal Filter

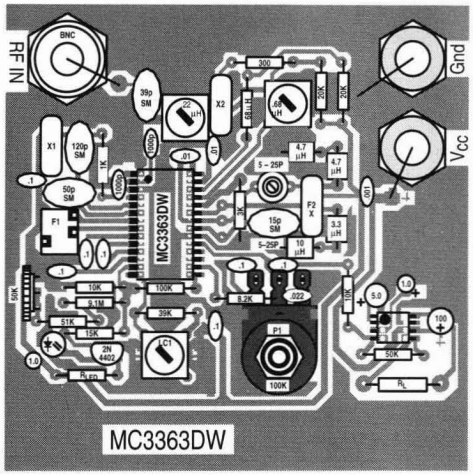



Figure 7. PC Board Circuit Side View

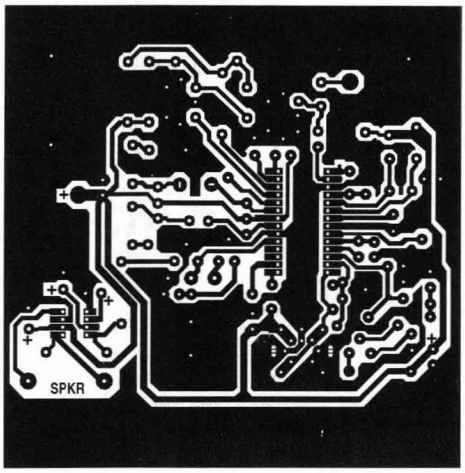
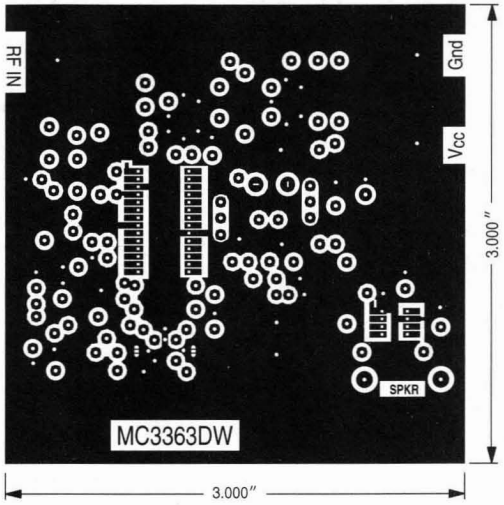



Figure 8. PC Board Component Side Ground Plane

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MOTOROLA

# MC3371
# MC3372

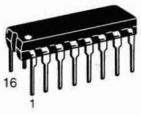
## Low Power Narrowband FM IF

**LOW POWER FM IF**

The MC3371 and MC3372 perform single conversion FM reception and consist of an oscillator, mixer, limiting IF amplifier, quadrature discriminator, active filter, squelch switch, and meter drive circuitry. These devices are designed for use in FM dual conversion communication equipment. The MC3371/MC3372 are similar to the MC3361/MC3357 FM IFs, except that a signal strength indicator replaces the scan function controlling driver which is in the MC3361/MC3357. The MC3371 is designed for the use of parallel LC components, while the MC3372 is designed for use with either a 455 kHz ceramic discriminator, or parallel LC components.

These devices also require fewer external parts than earlier products. The MC3371 and MC3372 are available in dual–in–line and surface mount packaging.

- Wide Operating Supply Voltage Range: $V_{CC}$ = 2.0 to 9.0 V
- Input Limiting Voltage Sensitivity of –3.0 dB
- Low Drain Current: $I_{CC}$ = 3.2 mA, @ $V_{CC}$ = 4.0 V, Squelch Off
- Minimal Drain Current Increase When Squelched
- Signal Strength Indicator: 60 dB Dynamic Range
- Mixer Operating Frequency Up to 100 MHz
- Fewer External Parts Required than Earlier Devices




**P SUFFIX**
PLASTIC PACKAGE
CASE 648

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948F
(TSSOP–16)

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**MAXIMUM RATINGS**

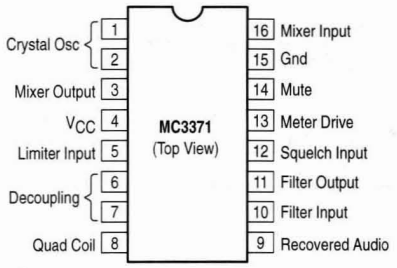
| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4 | $V_{CC}$(max) | 10 | Vdc |
| RF Input Voltage ($V_{CC}$ ≥ 4.0 Vdc) | 16 | V16 | 1.0 | Vrms |
| Detector Input Voltage | 8 | V8 | 1.0 | Vpp |
| Squelch Input Voltage ($V_{CC}$ ≥ 4.0 Vdc) | 12 | V12 | 6.0 | Vdc |
| Mute Function | 14 | $V_{14}$ | –0.7 to 10 | $V_{pk}$ |
| Mute Sink Current | 14 | I14 | 50 | mA |
| Junction Temperature | – | $T_J$ | 150 | °C |
| Storage Temperature Range | – | $T_{stg}$ | –65 to +150 | °C |

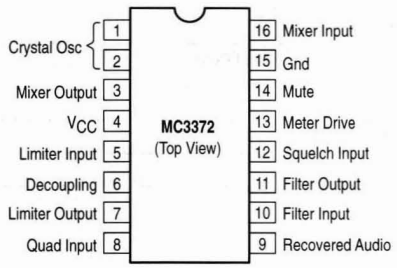
**NOTES:** 1. Devices should not be operated at these values. The "Recommended Operating Conditions" table provides conditions for actual device operation.
2. ESD data available upon request.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3371D | $T_A$ = –30° to +70°C | SO–16 |
| MC3371DTB | | TSSOP–16 |
| MC3371P | | Plastic DIP |
| MC3372D | | SO–16 |
| MC3372DTB | | TSSOP–16 |
| MC3372P | | Plastic DIP |

**PIN CONNECTIONS**



## RECOMMENDED OPERATING CONDITIONS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Supply Voltage (@ $T_A$ = 25°C)<br>(−30°C ≤ $T_A$ ≤ +75°C) | 4 | $V_{CC}$ | 2.0 to 9.0<br>2.4 to 9.0 | Vdc |
| RF Input Voltage | 16 | $V_{rf}$ | 0.0005 to 10 | mVrms |
| RF Input Frequency | 16 | $f_{rf}$ | 0.1 to 100 | MHz |
| Oscillator Input Voltage | 1 | $V_{local}$ | 80 to 400 | mVrms |
| Intermediate Frequency | – | $f_{if}$ | 455 | kHz |
| Limiter Amp Input Voltage | 5 | $V_{if}$ | 0 to 400 | mVrms |
| Filter Amp Input Voltage | 10 | $V_{fa}$ | 0.1 to 300 | mVrms |
| Squelch Input Voltage | 12 | $V_{sq}$ | 0 or 2 | Vdc |
| Mute Sink Current | 14 | $I_{sq}$ | 0.1 to 30 | mA |
| Ambient Temperature Range | – | $T_A$ | −30 to +70 | °C |

## AC ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 4.0 Vdc, $f_o$ = 58.1125 MHz, df = ±3.0 kHz, $f_{mod}$ = 1.0 kHz, 50 Ω source, $f_{local}$ = 57.6575 MHz, $V_{local}$ = 0 dBm, $T_A$ = 25°C, unless otherwise noted)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Input for 12 dB SINAD<br>Matched Input – (See Figures 11, 12 and 13)<br>Unmatched Input – (See Figures 1 and 2) | – | $V_{SIN}$ | <br>–<br>– | <br>1.0<br>5.0 | <br>–<br>15 | µVrms |
| Input for 20 dB NQS | – | $V_{NQS}$ | – | 3.5 | – | µVrms |
| Recovered Audio Output Voltage<br>$V_{rf}$ = −30 dBm | – | $AF_O$ | 120 | 200 | 320 | mVrms |
| Recovered Audio Drop Voltage Loss<br>Vrf = −30 dBm, $V_{CC}$ = 4.0 V to 2.0 V | – | $AF_{loss}$ | −8.0 | −1.5 | – | dB |
| Meter Drive Output Voltage (No Modulation)<br>$V_{rf}$ = −100 dBm<br>$V_{rf}$ = −70 dBm<br>$V_{rf}$ = −40 dBm | 13 | $M_{Drv}$<br>MV1<br>MV2<br>MV3 | <br>–<br>1.1<br>2.0 | <br>0.3<br>1.5<br>2.5 | <br>0.5<br>1.9<br>3.1 | Vdc |
| Filter Amp Gain<br>$R_S$ = 600 Ω, $f_s$ = 10 kHz, $V_{fa}$ = 1.0 mVrms | – | $A_{V(Amp)}$ | 47 | 50 | – | dB |
| Mixer Conversion Gain<br>$V_{rf}$ = −40 dBm, $R_L$ = 1.8 kΩ | – | $A_{V(Mix)}$ | 14 | 20 | – | dB |
| Signal to Noise Ratio<br>$V_{rf}$ = −30 dBm | – | s/n | 36 | 67 | – | dB |
| Total Harmonic Distortion<br>$V_{rf}$ = −30 dBm, BW = 400 Hz to 30 kHz | – | THD | – | 0.6 | 3.4 | % |
| Detector Output Impedance | 9 | $Z_O$ | – | 450 | – | Ω |
| Detector Output Voltage (No Modulation)<br>$V_{rf}$ = −30 dBm | 9 | $DV_O$ | – | 1.45 | – | Vdc |
| Meter Drive<br>$V_{rf}$ = −100 to −40 dBm | 13 | $M_O$ | – | 0.8 | – | µA/dB |
| Meter Drive Dynamic Range<br>$RF_{In}$<br>$IF_{In}$ (455 kHz) | 13 | MVD | <br>–<br>– | <br>60<br>80 | <br>–<br>– | dB |
| Mixer Third Order Input Intercept Point<br>f1 = 58.125 MHz<br>f2 = 58.1375 MHz | – | $ITO_{Mix}$ | <br><br>– | <br><br>−22 | <br><br>– | dBm |
| Mixer Input Resistance | 16 | $R_{in}$ | – | 3.3 | – | kΩ |
| Mixer Input Capacitance | 16 | $C_{in}$ | – | 2.2 | – | pF |

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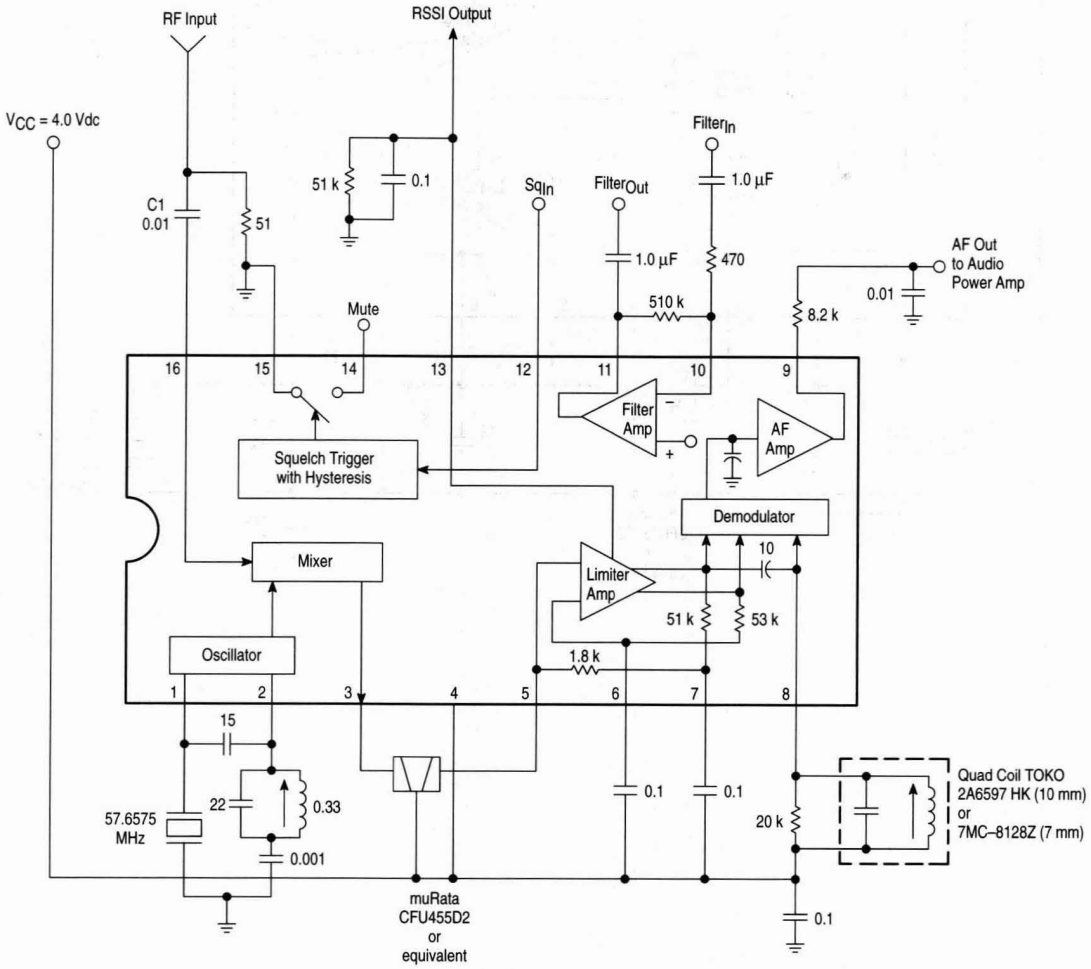
**DC ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 4.0 Vdc, $T_A$ = 25°C, unless otherwise noted)

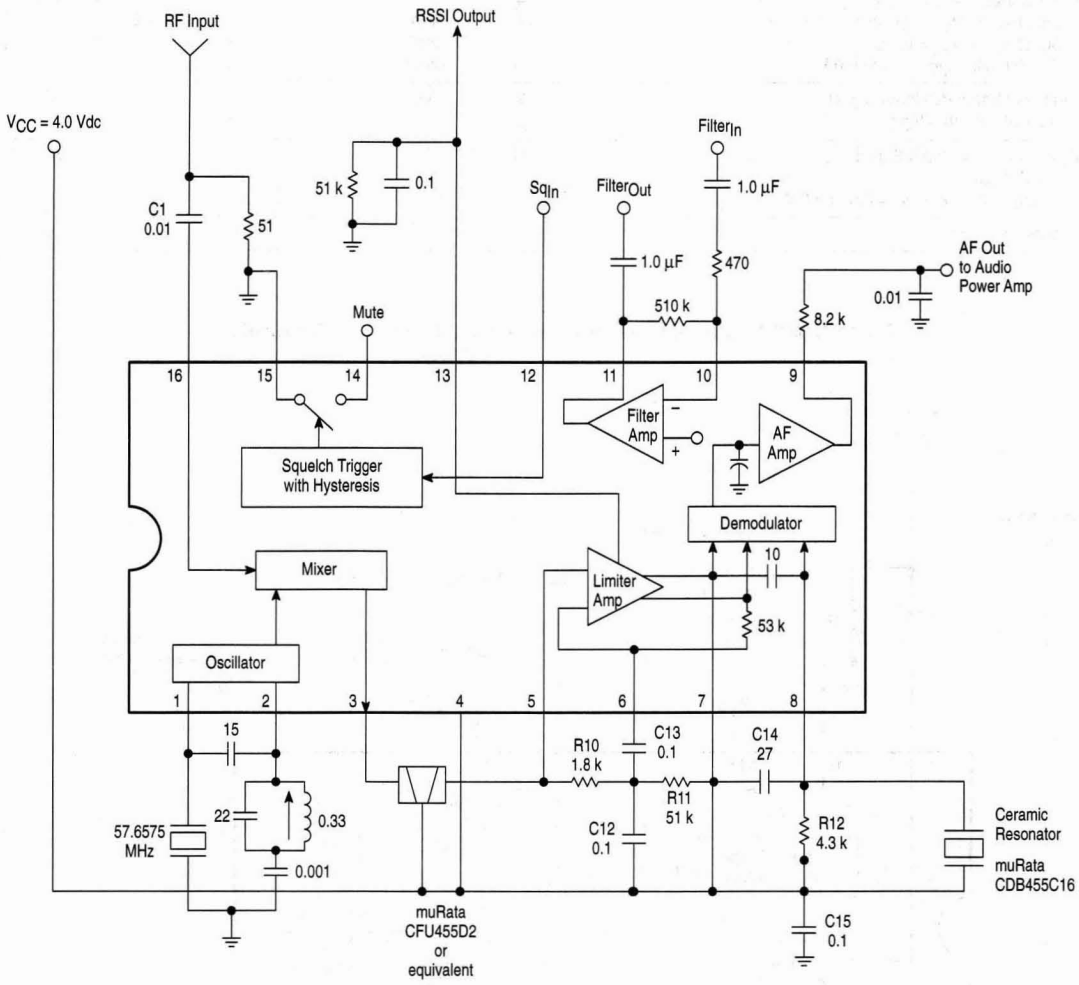
| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Drain Current (No Input Signal)<br>Squelch Off, $V_{sq}$ = 2.0 Vdc<br>Squelch On, $V_{sq}$ = 0 Vdc<br>Squelch Off, $V_{CC}$ = 2.0 to 9.0 V | 4 | <br>Icc1<br>Icc2<br>dIcc1 | <br>–<br>–<br>– | <br>3.2<br>3.6<br>1.0 | <br>4.2<br>4.8<br>2.0 | mA |
| Detector Output (No Input Signal)<br>DC Voltage, V8 = $V_{CC}$ | 9 | V9 | 0.9 | 1.6 | 2.3 | Vdc |
| Filter Output (No Input Signal)<br>DC Voltage<br>Voltage Change, $V_{CC}$ = 2.0 to 9.0 V | 11 | <br>V11<br>dV11 | <br>1.5<br>2.0 | <br>2.5<br>5.0 | <br>3.5<br>8.0 | Vdc |
| Trigger Hysteresis | – | Hys | 34 | 57 | 80 | mV |

**Figure 1. MC3371 Functional Block Diagram and Test Fixture Schematic**




8

**Figure 2. MC3372 Functional Block Diagram and Test Fixture Schematic**




8

## TYPICAL CURVES

(Unmatched Input)

**Figure 3. Total Harmonic Distortion versus Temperature**

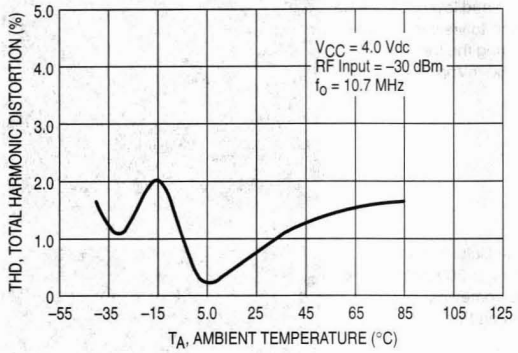



**Figure 4. RSSI versus RF Input**

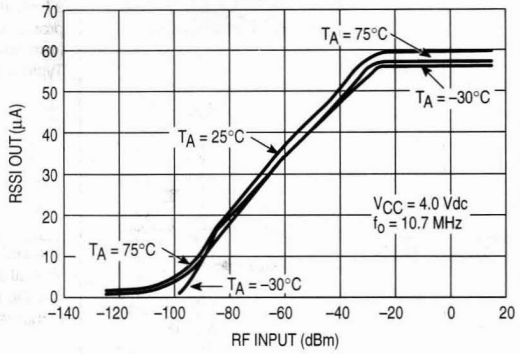



**Figure 5. RSSI Output versus Temperature**

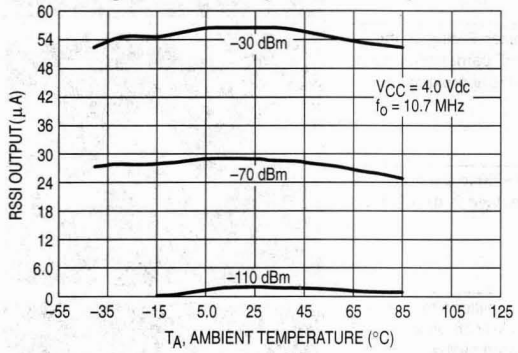



**Figure 6. Mixer Output versus RF Input**

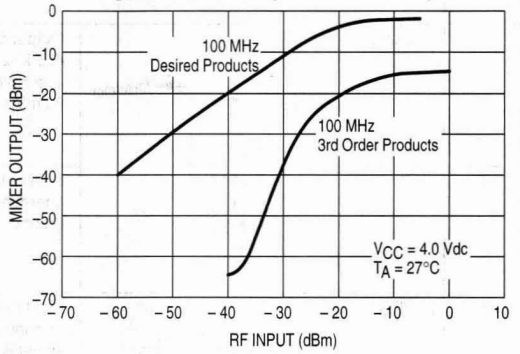



**Figure 7. Mixer Gain versus Supply Voltage**

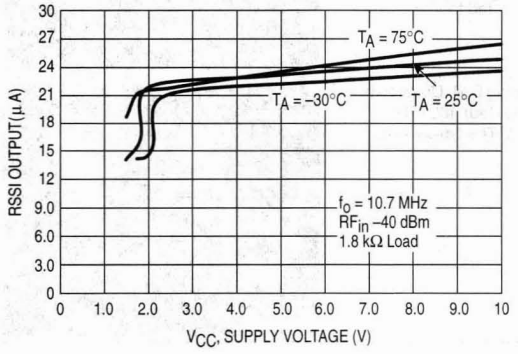
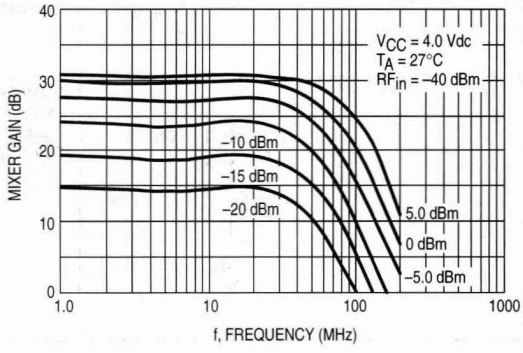



**Figure 8. Mixer Gain versus Frequency**

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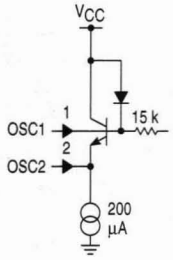
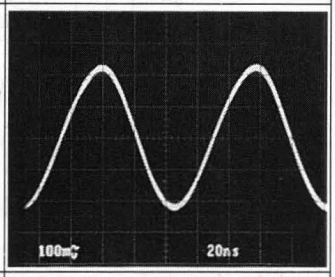
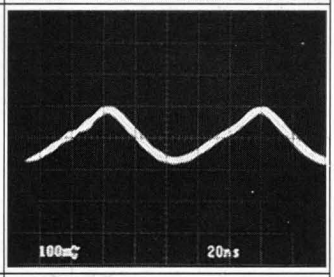
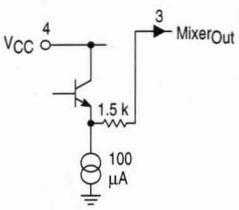
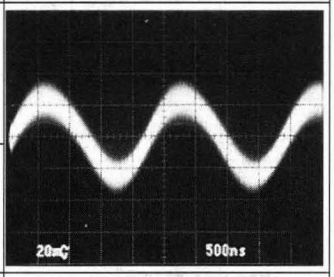
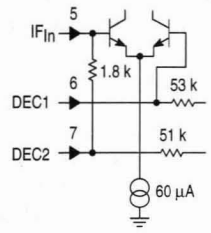
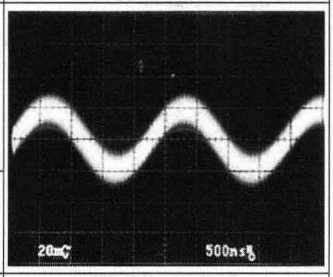
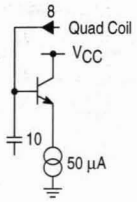
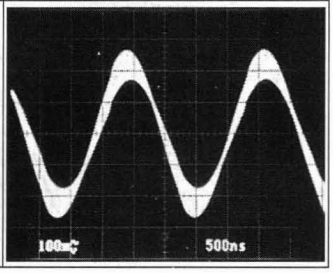
## MC3371 PIN FUNCTION DESCRIPTION

**OPERATING CONDITIONS** $V_{CC}$ = 4.0 Vdc, $RF_{In}$ = 100 µV, $f_{mod}$ = 1.0 kHz, $f_{dev}$ = 3.0 kHz. MC3371 at $f_{RF}$ = 10.7 MHz (see Figure 11).

| Pin | Symbol | Internal Equivalent Circuit | Description | Waveform |
|---|---|---|---|---|
| 1 | OSC1 |  | The base of the Colpitts oscillator. Use a high impedance and low capacitance probe or a "sniffer" to view the wave–form without altering the frequency. Typical level is 450 mVpp. |  |
| 2 | OSC2 | | The emitter of the Colpitts oscillator. Typical signal level is 200 mVpp. Note that the signal is somewhat distorted compared to that on Pin 1. |  |
| 3 | $MX_{Out}$ |  | Output of the Mixer. Riding on the 455 kHz is the RF carrier component. The typical level is approximately 60 mVpp. |  |
| 4 | $V_{CC}$ | | Supply Voltage –2.0 to 9.0 Vdc is the operating range. $V_{CC}$ is decoupled to ground. | |
| 5 | $IF_{In}$ |  | Input to the IF amplifier after passing through the 455 kHz ceramic filter. The signal is attenuated by the filter. The typical level is approximately 50 mVpp. |  |
| 6<br>7 | DEC1<br>DEC2 | | IF Decoupling. External 0.1 µF capacitors connected to $V_{CC}$. | |
| 8 | Quad Coil |  | Quadrature Tuning Coil. Composite (not yet demodulated) 455 kHz IF signal is present. The typical level is 500 mVpp. |  |

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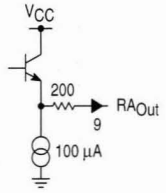
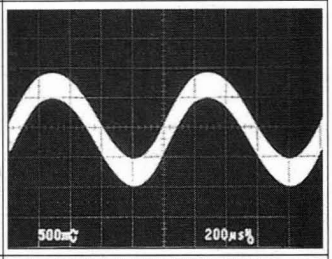
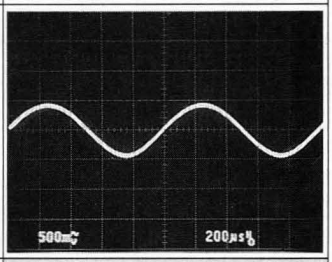
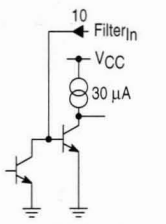
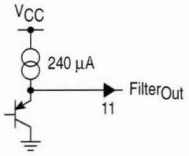
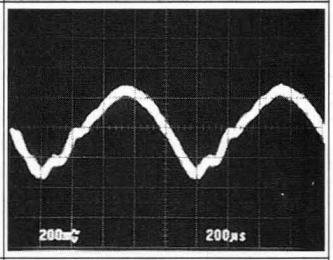
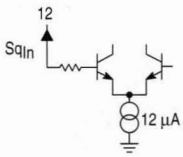
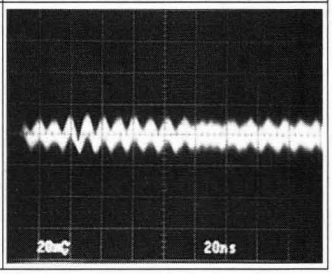
## MC3371 PIN FUNCTION DESCRIPTION (continued)

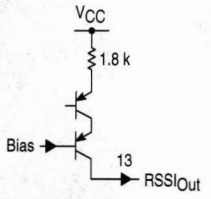
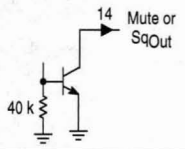
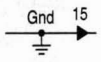
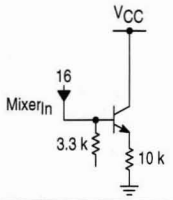
**OPERATING CONDITIONS** $V_{CC}$ = 4.0 Vdc, $RF_{In}$ = 100 μV, $f_{mod}$ = 1.0 kHz, $f_{dev}$ = 3.0 kHz. MC3371 at $f_{RF}$ = 10.7 MHz (see Figure 11).

| Pin | Symbol | Internal Equivalent Circuit | Description | Waveform |
|---|---|---|---|---|
| 9 | RA |  | Recovered Audio. This is a composite FM demodulated output having signal and carrier component. The typical level is 1.4 Vpp. |  |
| | | | The filtered recovered audio has the carrier component removed and is typically 800 mVpp. |  |
| 10 | $Fil_{In}$ |  | Filter Amplifier Input | |
| 11 | $Fil_{Out}$ |  | Filter Amplifier Output. The typical signal level is 400 mVpp. |  |
| 12 | $Sq_{In}$ |  | Squelch Input. See discussion in application text. |  |

8

## MC3371 PIN FUNCTION DESCRIPTION (continued)

**OPERATING CONDITIONS** $V_{CC}$ = 4.0 Vdc, $RF_{In}$ = 100 µV, $f_{mod}$ = 1.0 kHz, $f_{dev}$ = 3.0 kHz. MC3371 at $f_{RF}$ = 10.7 MHz (see Figure 11).

| Pin | Symbol | Internal Equivalent Circuit | Description | Waveform |
|---|---|---|---|---|
| 13 | RSSI |  | RSSI Output. Referred to as the Received Signal Strength Indicator or RSSI. The chip sources up to 60 µA over the linear 60 dB range. This pin may be used many ways, such as: AGC, meter drive and carrier triggered squelch circuit. | |
| 14 | MUTE |  | Mute Output. See discussion in application text. | |
| 15 | Gnd |  | Ground. The ground area should be continuous and unbroken. In a two–sided layout, the component side has the ground plane. In a one–sided layout, the ground plane fills around the traces on the circuit side of the board and is not interrupted. | |
| 16 | $MIX_{In}$ |  | Mixer Input –<br>Series Input Impedance:<br>@ 10 MHz: 309 – j33 Ω<br>@ 45 MHz: 200 – j13 Ω | |

*Other pins are the same as pins in MC3371.

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## MC3372 PIN FUNCTION DESCRIPTION

**OPERATING CONDITIONS** $V_{CC}$ = 4.0 Vdc, $RF_{In}$ = 100 µV, $f_{mod}$ = 1.0 kHz, $f_{dev}$ = 3.0 kHz. MC3372 at $f_{RF}$ = 45 MHz (see Figure 13).

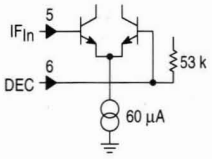
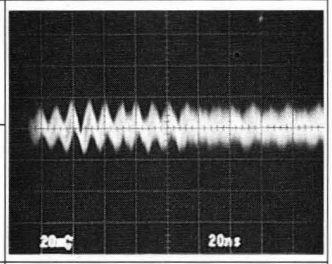
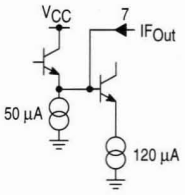
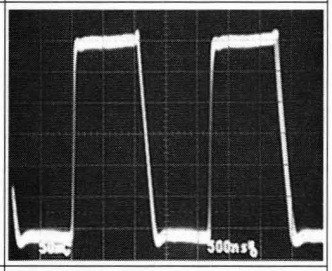
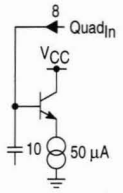
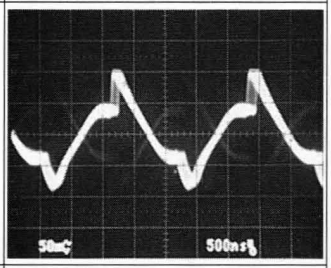
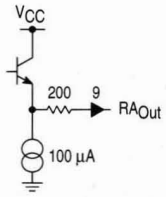
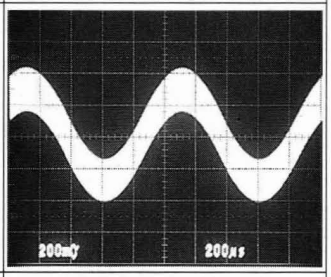
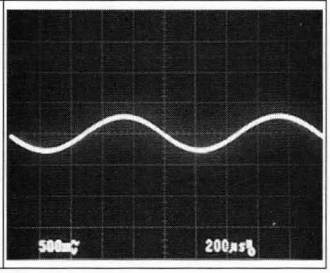
| Pin | Symbol | Internal Equivalent Circuit | Description | Waveform |
|---|---|---|---|---|
| 5 | $IF_{In}$ |  | IF Amplifier Input |  |
| 6 | DEC1 | | IF Decoupling. External 0.1 µF capacitors connected to $V_{CC}$. | |
| 7 | $IF_{Out}$ |  | IF Amplifier Output Signal level is typically 300 mVpp. |  |
| 8 | $Quad_{In}$ |  | Quadrature Detector Input. Signal level is typically 150 mVpp. |  |
| 9 | RA |  | Recovered Audio. This is a composite FM demodulated output having signal and carrier components. Typical level is 800 mVpp. |  |
| | | | The filtered recovered audio has the carrier signal removed and is typically 500 mVpp. |  |

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**Figure 9. MC3371 Circuit Schematic**

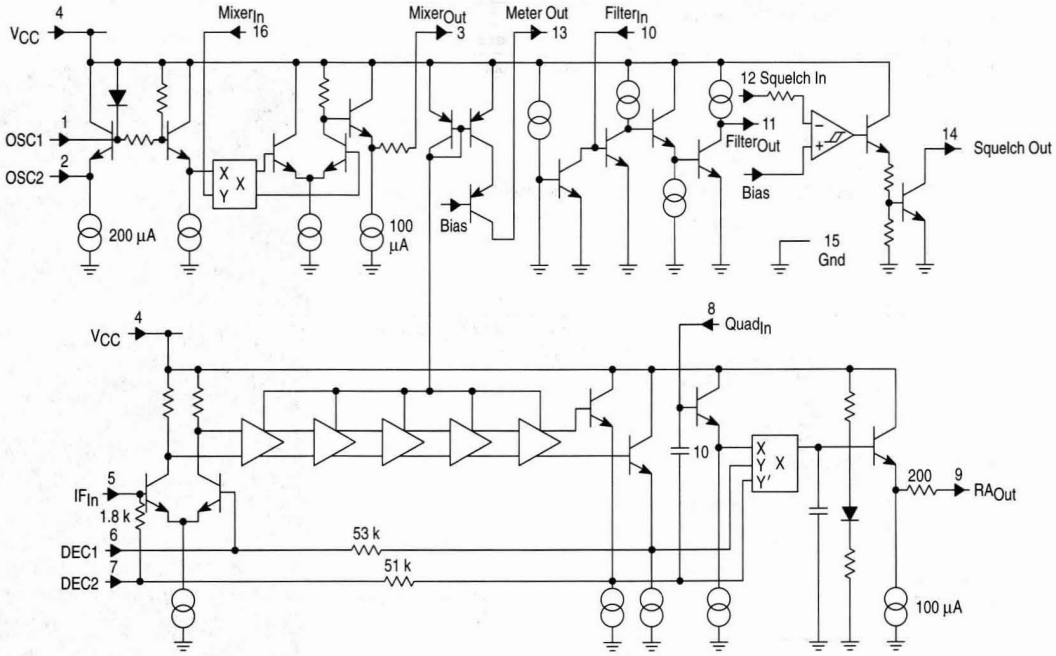
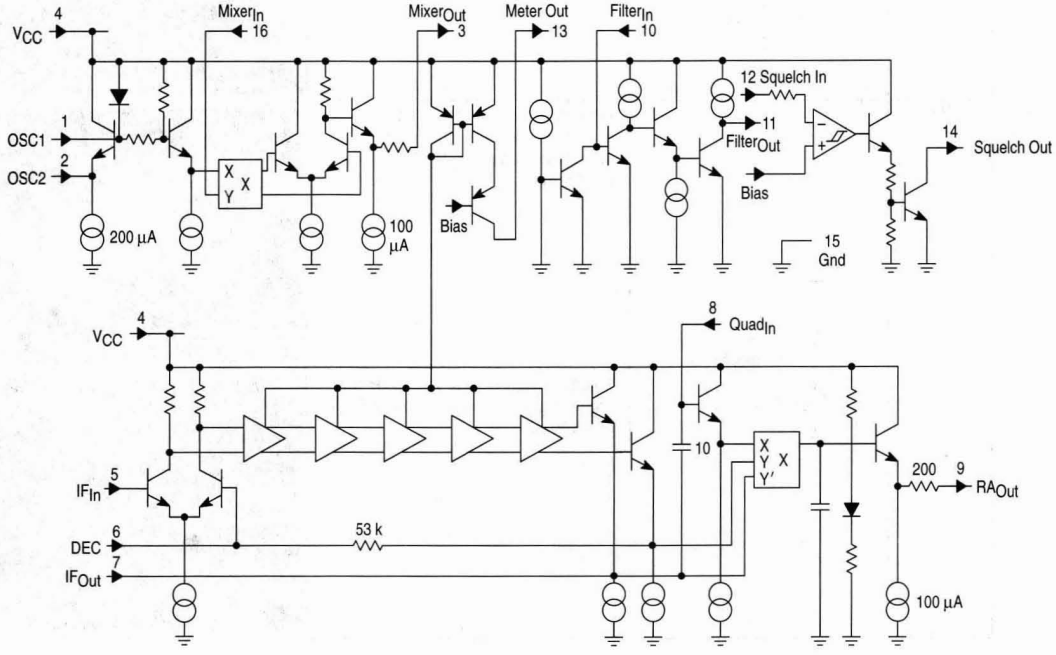



**Figure 10. MC3372 Circuit Schematic**



## CIRCUIT DESCRIPTION

The MC3371 and MC3372 are low power narrowband FM receivers with an operating frequency of up to 60 MHz. Its low voltage design provides low power drain, excellent sensitivity, and good image rejection in narrowband voice and data link applications.

This part combines a mixer, an IF (intermediate frequency) limiter with a logarithmic response signal strength indicator, a quadrature detector, an active filter and a squelch trigger circuit. In a typical application, the mixer amplifier converts an RF input signal to a 455 kHz IF signal. Passing through an external bandpass filter, the IF signal is fed into a limiting amplifier and detection circuit where the audio signal is recovered. A conventional quadrature detector is used.

The absence of an input signal is indicated by the presence of noise above the desired audio frequencies. This "noise band" is monitored by an active filter and a detector. A squelch switch is used to mute the audio when noise or a tone is present. The input signal level is monitored by a meter drive circuit which detects the amount of IF signal in the limiting amplifier.

## APPLICATIONS INFORMATION

The oscillator is an internally biased Colpitts type with the collector, base, and emitter connections at Pins 4, 1 and 2 respectively. This oscillator can be run under crystal control. For fundamental mode crystals use crystal characterized parallel resonant for 32 pF load. For higher frequencies, use 3rd overtone series mode type crystals. The coil (L2) and resistor RD (R13) are needed to ensure proper and stable operation at the LO frequency (see Figure 13, 45 MHz application circuit).

The mixer is doubly balanced to reduce spurious radiation. Conversion gain stated in the AC Electrical Characteristics table is typically 20 dB. This power gain measurement was made under stable conditions using a 50 Ω source at the input and an external load provided by a 455 kHz ceramic filter at the mixer output which is connected to the $V_{CC}$ (Pin 4) and IF input (Pin 5). The filter impedance closely matches the 1.8 kΩ internal load resistance at Pin 3 (mixer output). Since the input impedance at Pin 16 is strongly influenced by a 3.3 kΩ internal biasing resistor and has a low capacitance, the useful gain is actually much higher than shown by the standard power gain measurement. The Smith Chart plot in Figure 17 shows the measured mixer input impedance versus input frequency with the mixer input matched to a 50 Ω source impedance at the given frequencies. In order to assure stable operation under matched conditions, it is necessary to provide a shunt resistor to ground. Figures 11, 12 and 13 show the input networks used to derive the mixer input impedance data.

Following the mixer, a ceramic bandpass filter is recommended for IF filtering (i.e. 455 kHz types having a bandwidth of ±2.0 kHz to ±15 kHz with an input and output impedance from 1.5 kΩ to 2.0 kΩ). The 6 stage limiting IF amplifier has approximately 92 dB of gain. The MC3371 and MC3372 are different in the limiter and quadrature detector circuits. The MC3371 has a 1.8 kΩ and a 51 kΩ resistor providing internal dc biasing and the output of the limiter is internally connected, both directly and through a 10 pF capacitor to the quadrature detector; whereas, in the MC3372 these components are not provided internally. Thus, in the MC3371, no external components are necessary to match the 455 kHz ceramic filter, while in the MC3372, external 1.8 kΩ and 51 kΩ biasing resistors are needed between Pins 5 and 7, respectively (see Figures 12 and 13).

In the MC3371, a parallel LCR quadrature tank circuit is connected externally from Pin 8 to $V_{CC}$ (similar to the MC3361). In the MC3372, a quadrature capacitor is needed externally from Pin 7 to Pin 8 and a parallel LC or a ceramic discriminator with a damping resistor is also needed from Pin 8 to $V_{CC}$ (similar to the MC3357). The above external quadrature circuitry provides 90° phase shift at the IF center frequency and enables recovered audio.

The damping resistor determines the peak separation of the detector and is somewhat critical. As the resistor is decreased, the separation and the bandwidth is increased but the recovered audio is decreased. Receiver sensitivity is dependent on the value of this resistor and the bandwidth of the 455 kHz ceramic filter.

On the chip the composite recovered audio, consisting of carrier component and modulating signal, is passed through a low pass filter amplifier to reduce the carrier component and then is fed to Pin 9 which has an output impedance of 450 Ω. The signal still requires further filtering to eliminate the carrier component, deemphasis, volume control, and further amplification before driving a loudspeaker. The relative level of the composite recovered audio signal at Pin 9 should be considered for proper interaction with an audio post amplifier and a given load element. The MC13060 is recommended as a low power audio amplifier.

The meter output indicates the strength of the IF level and the output current is proportional to the logarithm of the IF input signal amplitude. A maximum source current of 60 μA is available and can be used to drive a meter and to detect a carrier presence. This is referred to as a Received Strength Signal Indicator (RSSI). The output at Pin 13 provides a current source. Thus, a resistor to ground yields a voltage proportional to the input carrier signal level. The value of this resistor is estimated by ($V_{CC}$(Vdc) – 1.0 V)/60 μA; so for $V_{CC}$ = 4.0 Vdc, the resistor is approximately 50 kΩ and provides a maximum voltage swing of about 3.0 V.

A simple inverting op amp has an output at Pin 11 and the inverting input at Pin 10. The noninverting input is connected to 2.5 V. The op amp may be used as a noise triggered squelch or as an active noise filter. The bandpass filter is designed with external impedance elements to discriminate between frequencies. With an external AM detector, the filtered audio signal is checked for a tone signal or for the presence of noise above the normal audio band. This information is applied to Pin 12.

An external positive bias to Pin 12 sets up the squelch trigger circuit such that the audio mute (Pin 14) is open or connected to ground. If Pin 12 is pulled down to 0.9 V or below by the noise or tone detector, Pin 14 is internally shorted to ground. There is about 57 mV of hyteresis at Pin 12 to prevent jitter. Audio muting is accomplished by connecting Pin 14 to the appropriate point in the audio path between Pin 9 and an audio amplifier. The voltage at Pin 14 should not be lower than –0.7 V; this can be assured by connecting Pin 14 to the point that has no dc component.

Another possible application of the squelch switch may be as a carrier level triggered squelch circuit, similar to the MC3362/MC3363 FM receivers. In this case the meter output can be used directly to trigger the squelch switch when the RF input at the input frequency falls below the desired level. The level at which this occurs is determined by the resistor placed between the meter drive output (Pin 13) and ground (Pin 15).

**Figure 11. Typical Application for MC3371 at 10.7 MHz**

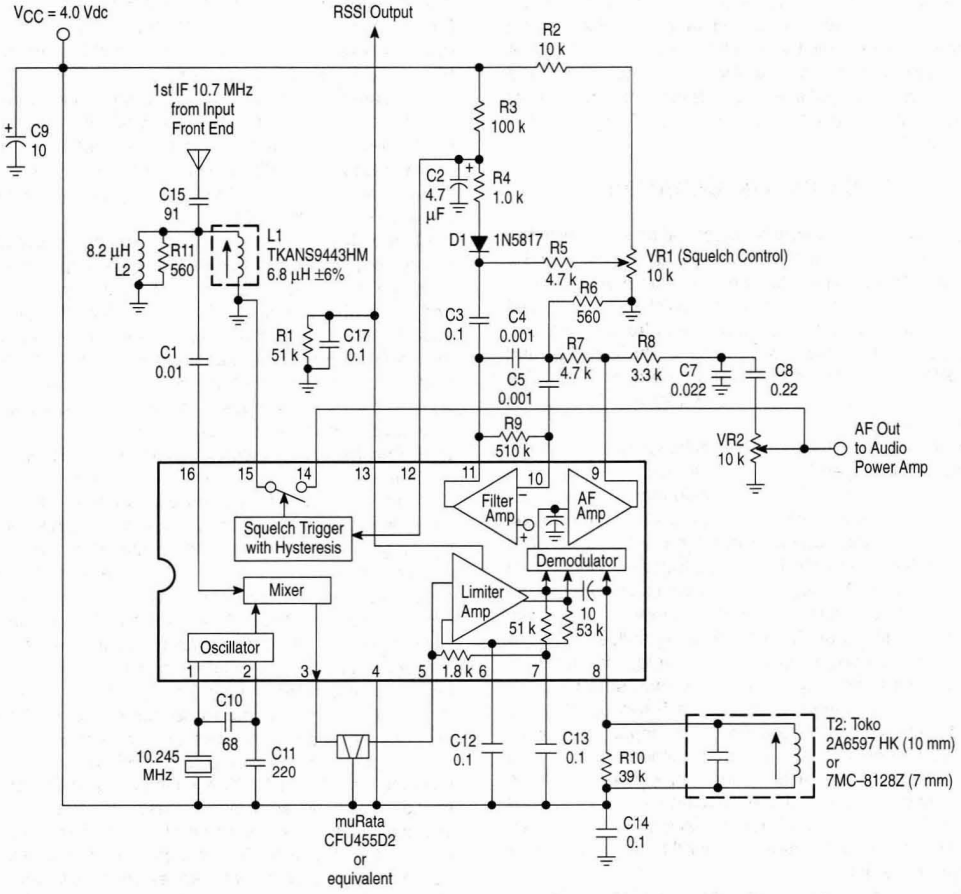


**Figure 12. Typical Application for MC3372 at 10.7 MHz**

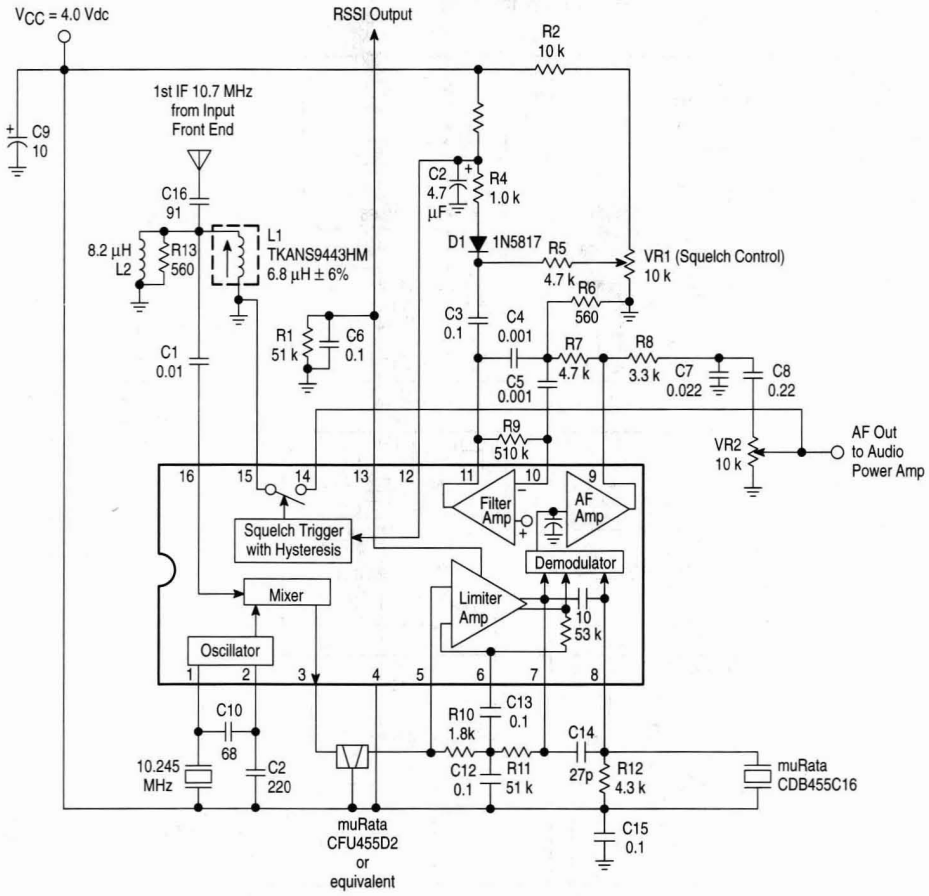



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**Figure 13. Typical Application for MC3372 at 45 MHz**

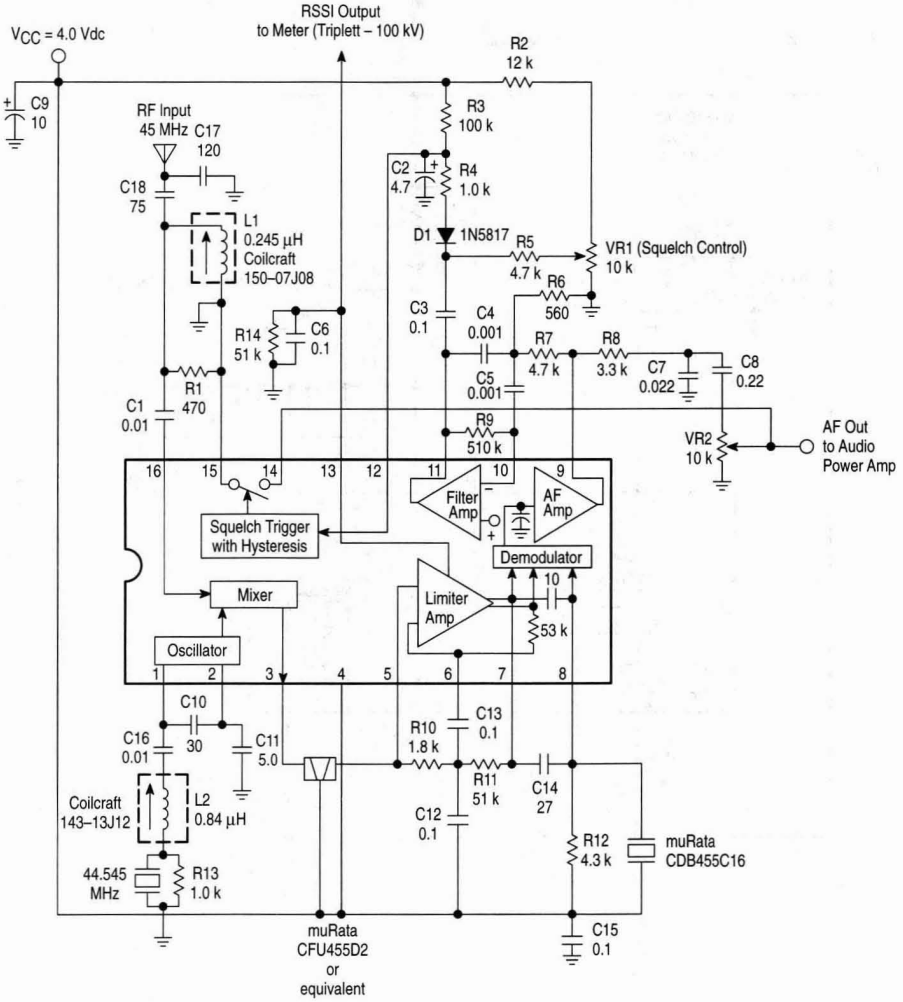



**Figure 14. RSSI Output versus RF Input**

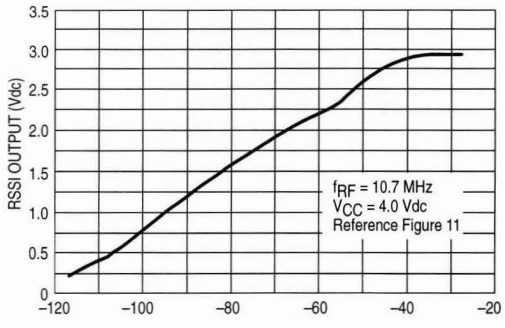



**Figure 15. RSSI Output versus RF Input**

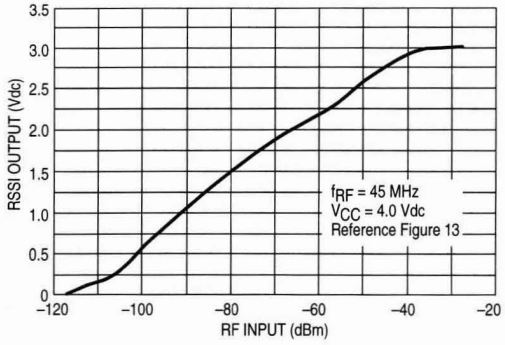
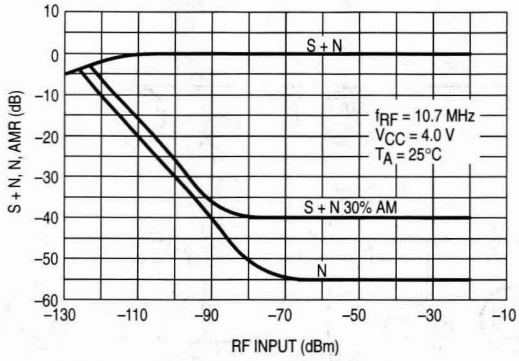


**Figure 16. S + N, N, AMR versus Input**




* Reference Figures 11, 12 and 13

**Figure 17. Mixer Input Impedance versus Frequency**

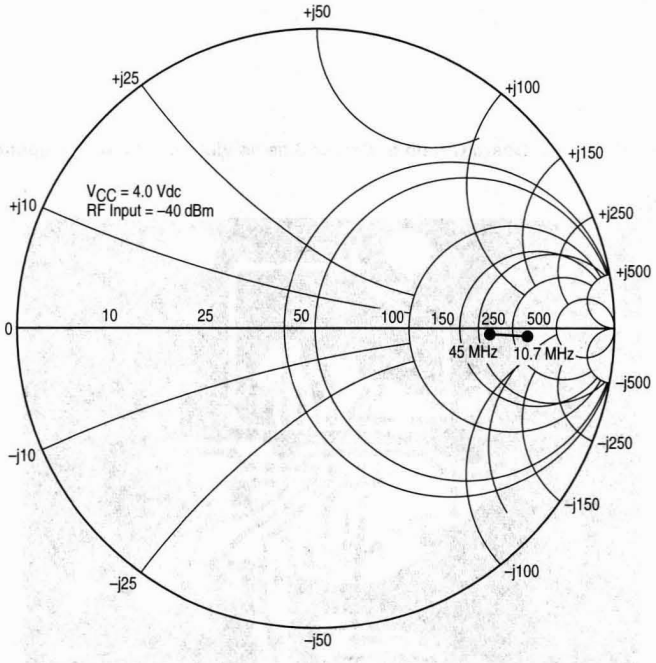



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**Figure 18. MC3371 PC Board Component View with Matched Input at 10.7 MHz**

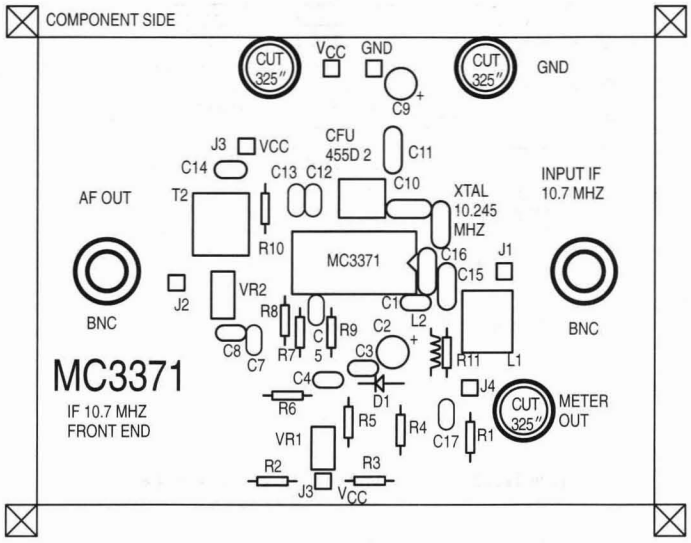
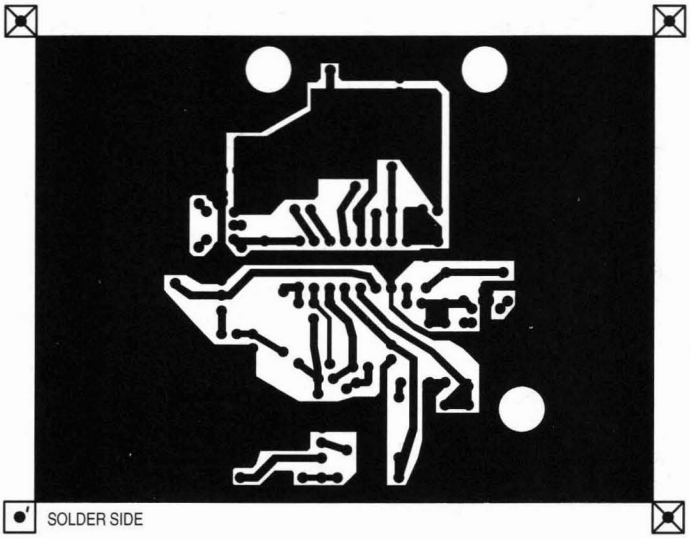



**Figure 19. MC3371 PC Board Circuit or Solder Side as Viewed through Component Side**




Above PC Board is laid out for the circuit in Figure 11.

**Figure 20. MC3372P PC Board Component View with Matched Input at 10.7 MHz**

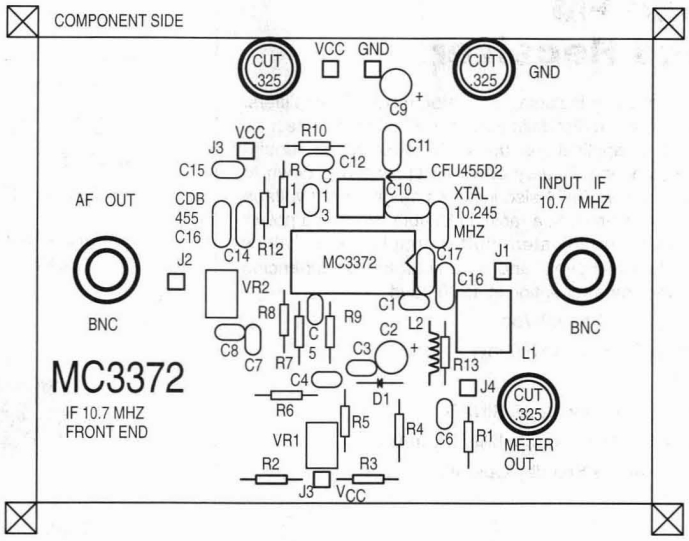
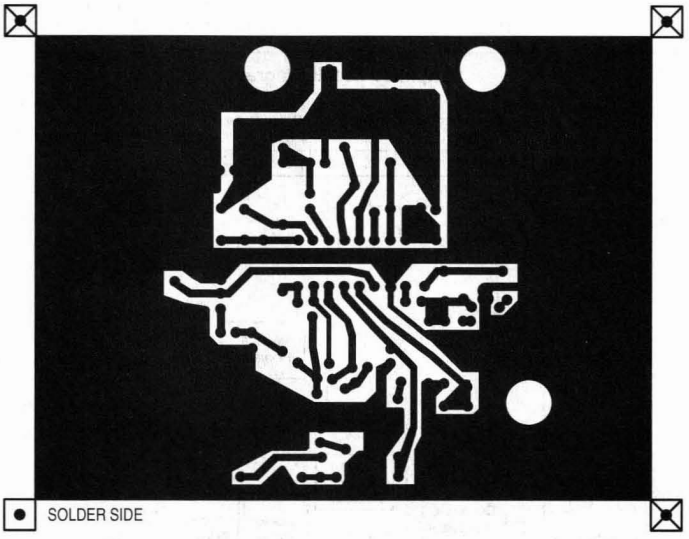



**Figure 21. MC3372P PC Board Circuit or Solder Side as Viewed through Component Side**




Above PC Board is laid out for the circuit in Figure 12.

MOTOROLA

# Low Voltage FM Narrowband Receiver

. . . with single conversion circuitry including oscillator, mixer, IF amplifiers, limiting IF circuitry, and quadrature discriminator. The MC3374 is perfect for narrowband audio and data applications up to 75 MHz which require extremely low power consumption. Battery powered applications down to $V_{CC}$ = 1.1 V are possible. The MC3374 also includes an on–board voltage regulator, low battery detection circuitry, a receiver enable allowing a power down Sleep–Mode™, two undedicated buffer amplifiers to allow simultaneous audio and data reception, and a comparator for enhancing FSK (Frequency Shift Keyed) data reception to 1200 baud.

- Low Supply Voltage: $V_{CC}$ = 1.1 to 3.0 Vdc
- Low Power Consumption: $P_D$ = 1.5 to 5.0 mW
- Input Bandwidth 75 MHz
- Excellent Sensitivity: 0.5 μVrms for 12 dB SINAD
- Voltage Regulator Available (Source Capability 3.0 mA)
- Receiver Enable to Allow Active/Standby Operation
- Low Battery Detection Circuitry
- Self Biasing Audio Buffer
- Data Buffer
- FSK Data Shaping Comparator
- Standard 32–Lead QFP Surface Mount Package

Sleep–Mode is a trademark of Motorola, Inc.

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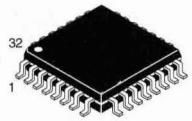
**MC3374**

**LOW VOLTAGE SINGLE CONVERSION FM RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

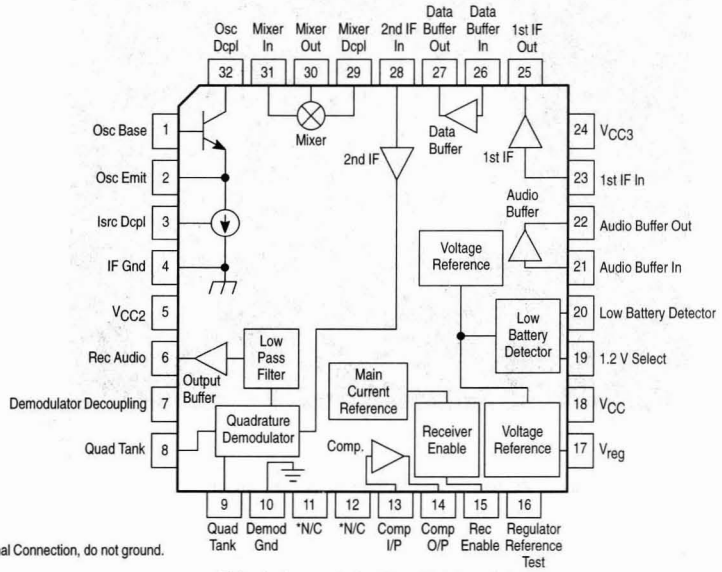



**FTB SUFFIX**
PLASTIC PACKAGE
CASE 873
(Thin QFP)

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC3374FTB | $T_A$ = −10° to +70°C | TQFP–32 |

**Simplified Block Diagram**




*Internal Connection, do not ground.

This device contains 87 active transistors

**MAXIMUM RATINGS** (Voltage with respect to Pins 4 and 10; $T_A$ = 25°C.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Supply Voltage | 18 | 5.0 | Vdc |
| RF Input Signal | 31 | 1.0 | Vrms |
| Audio Buffer Input | 21 | 1.0 | Vrms |
| Data Buffer Input | 26 | 1.0 | Vrms |
| Comparator Input | 13 | 1.0 | Vrms |
| Junction Temperature | – | 150 | °C |
| Storage Temperature | – | −65 to +150 | °C |

Device should not be operated at or outside these values. The "Recommended Operating Limits" provide for actual device operation.

**RECOMMENDED OPERATING CONDITIONS**

| Parameter | Pin | Value | Unit |
|---|---|---|---|
| Supply Voltage | 18 | 1.1 to 3.0 | Vdc |
| Receiver Enable Voltage | 15 | $V_{CC}$ | Vdc |
| 1.2 V Select Voltage | 19 | Open or $V_{CC}$ | Vdc |
| RF Input Signal Level | 31 | 0.001 to 100 | mVrms |
| RF Input Frequency | 31 | 0 to 75 | MHz |
| Intermediate Frequency (IF) | – | 455 | kHz |
| Audio Buffer Input | 21 | 0 to 75 | mVrms |
| Data Buffer Input | 26 | 0 to 75 | mVrms |
| Comparator Input | 13 | 10 to 300 | mVrms |
| Ambient Temperature | – | −10 to 70 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 1.3 V, $f_o$ = 10.7 MHz, $f_{mod}$ = 1.0 kHz, Deviation = 3.0 kHz, $T_A$ = 25°C, Test Circuit of Figure 1, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OVERALL MC3374 PERFORMANCE** | | | | | |
| Drain Current – Pin 15 = $V_{CC}$ (Enabled)<br>– Pin 15 = 0 Vdc (Disabled) | 5 + 18 + 24<br>5 + 18 + 24 | –<br>– | 1.6<br>0.5 | 3.0<br>– | mA<br>µA |
| Recovered Audio (RF Input = 10 µV) | 6 | 13 | 18 | 30 | mVrms |
| Noise Output (RF Input = 0 mV, 300 Hz–5.0 kHz) | 6 | – | 1.0 | – | mVrms |
| Input for –3.0 dB Limiting | 31 | – | 0.6 | – | µVrms |
| **MIXER** | | | | | |
| Mixer Input Resistance (Rp) | 31 | – | 1.5 | – | kΩ |
| Mixer Input Capacitance (Cp) | 31 | – | 9.0 | – | pF |
| **FIRST IF AMPLIFIER** | | | | | |
| First IF Amp Voltage Gain | – | – | 27 | – | dB |
| **AUDIO BUFFER** | | | | | |
| Voltage Gain | – | 3.0 | 4.0 | 4.7 | V/V |
| Input Resistance | 21 | – | 110 | – | kΩ |
| Maximum Input for Undistorted Output (<5% THD) | 21 | – | 64 | – | mVrms |
| Maximum Output Swing (<5% THD) | 22 | – | 690 | – | $mV_{pp}$ |
| Output Resistance | 22 | – | 780 | – | Ω |
| **DATA BUFFER** | | | | | |
| Voltage Gain | – | 1.4 | 2.7 | 4.3 | V/V |
| Input Resistance | 26 | – | 9.8 | – | MΩ |
| Maximum Input for Undistorted Output (<5% THD) | 26 | – | 100 | – | mVrms |
| Maximum Output Swing (<5% THD) | 27 | – | 800 | – | $mV_{pp}$ |
| Output Resistance | 27 | – | 690 | – | Ω |

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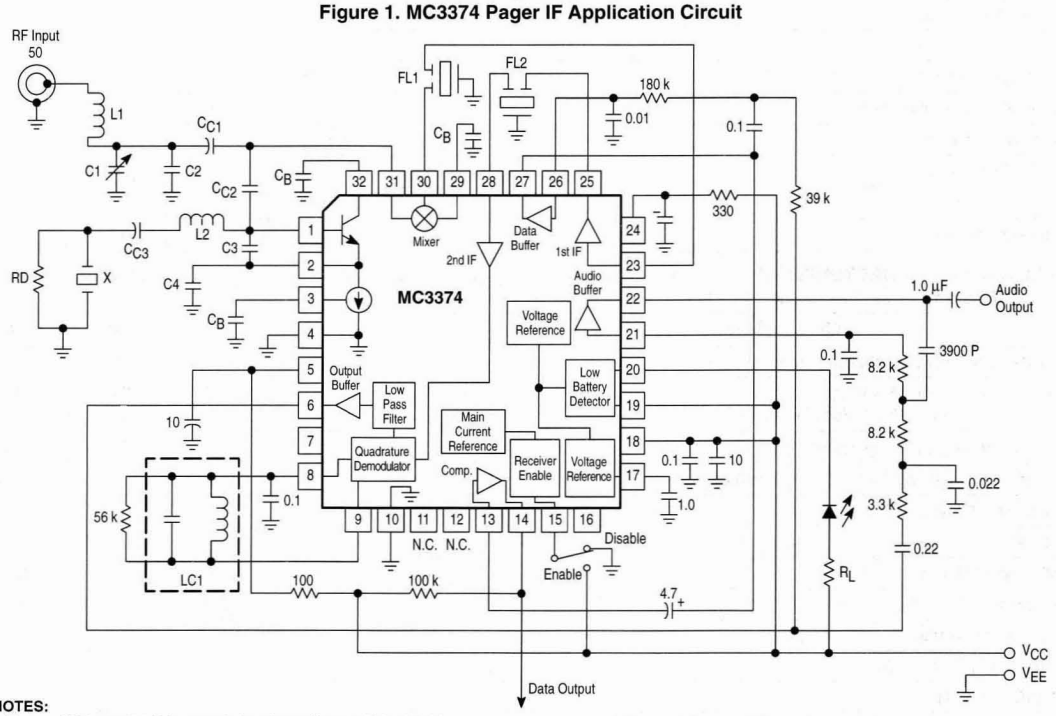
**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 1.3 V, $f_o$ = 10.7 MHz, $f_{mod}$ = 1.0 kHz, Deviation = 3.0 kHz, $T_A$ = 25°C, Test Circuit of Figure 1, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **COMPARATOR** | | | | | |
| Minimum Input for Triggering ($R_L$ = 100 kΩ) | 13 | – | 7.0 | – | mVrms |
| Maximum Input Frequency ($R_L$ = 100 kΩ) | 13 | – | 25 | – | kHz |
| Rise Time (10–90%; $R_L$ = 100 kΩ) | 14 | – | 5.0 | – | µs |
| Fall Time (90–10%; $R_L$ = 100 kΩ) | 14 | – | 0.4 | – | µs |
| **LOW BATTERY DETECTOR** | | | | | |
| Low Battery Trip Point | 19 | – | 1.2 | – | Vdc |
| Low Battery Output – $V_{CC}$ = 0.9 V<br>– $V_{CC}$ = 1.3 V | 20<br>20 | –<br>– | 0.2<br>$V_{CC}$ | –<br>– | Vdc |
| **VOLTAGE REGULATOR** | | | | | |
| Regulated Output (see Figure 4) | 17 | 0.95 | 1.07 | 1.15 | Vdc |
| Source Capability | 17 | – | – | 3.0 | mA |

**Figure 1. MC3374 Pager IF Application Circuit**




**NOTES:**

1. FL1 and FL2 are 455 kHz ceramic bandpass filters, which should have input and output impedances of 1.5 kΩ to 2.0 kΩ. Suggested part numbers are MuRata CFU455X or CFW455x – the 'X' suffix denotes bandwidth.
2. LC1 is a 455 kHz LC resonator. Recommended part numbers are Toko America RMC2A6597HM or 5SVLC–0637BGT (smaller). The evaluation board layout shown provides for use of either resonator. Ceramic discriminator elements cannot be used with the MC3374 due to their low input impedance. The damping resistor value can be raised to increase the recovered audio or lowered to increase the quadrature detector's bandwidth and linearity – practical limits are approximately 27 kΩ to 75 kΩ. Typically the quadrature detector's bandwidth should match the low IF filter's bandwidth.
3. The data buffer is set up as a low–pass filter with a corner frequency of approximately 200 Hz. The audio buffer is a bandpass filter with corner frequencies of 300 Hz and 3.0 kHz. The audio amplifier provides bass suppression.
4. $C_{C1}$ and $C_{C3}$ are RF coupling capacitors and should have ≤ 20 Ω impedance at the desired input and oscillator frequencies.
5. $C_{C2}$ provides "light coupling" of the oscillator signal into the mixer, and should have a 3.0 kΩ to 5.0 kΩ impedance at the desired local oscillator frequency.
6. Capacitors labelled $C_B$ are bypass capacitors and should have 20 Ω impedance at the desired RF and local oscillator frequencies.
7. The network of L1, C1 and C2 provides impedance matching of the mixer input (nominally 3.0 kΩ shunted by 9.0 pF) to 50 Ω at the desired RF/IF input frequency. This will allow for bench testing of the receiver from typical RF signal generators or radio service monitors, but additional or different matching will be required to maximize receiver sensitivity when used in conjunction with an antenna, RF preamplifier or mixer.

| In. Freq. | L1 | L2 | C1 | C2 | C3 | C4 | $C_{C1}/C_{C3}$ | $C_{C2}$ | $C_B$ | RD |
|---|---|---|---|---|---|---|---|---|---|---|
| 10.7 MHz | 6.8 µH | Short | 2–82 pF | 10 pF | 120 pF | 50 pF | 1.0 nF | 5.0 pF | 0.1 µF | Open |
| 45 MHz | 0.68 µH | 1.2 µH | 5–25 pF | Open | 30 pF | 5.0 pF | 1.0 nF | 1.0 pF | 1.0 nF | 1.0 k |
| 72 MHz | 0.22 µH | 0.22 µH | 5–25 pF | Open | 18 pF | 3.0 pF | 470 pF | 1.0 pF | 470 pF | 1.0 k |

**Figure 2. Recovered Audio versus Supply**

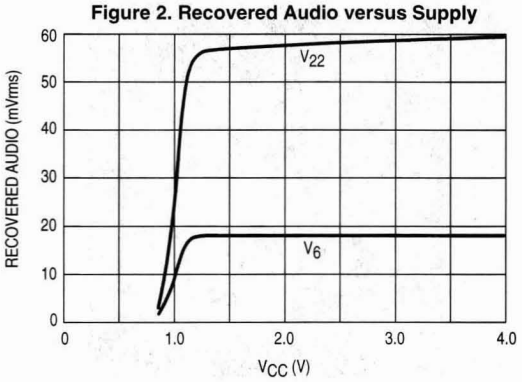



**Figure 3. S+N, N versus Input**

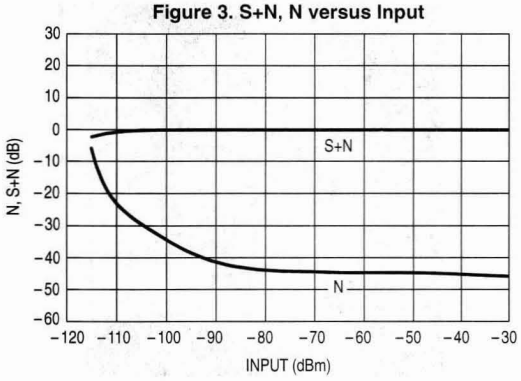



**Figure 4. $V_{REG}$ versus Supply**

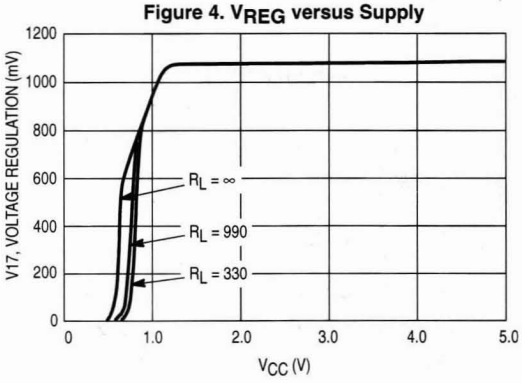



**Figure 5. Regulated Output and Recovered Audio versus Temperature**

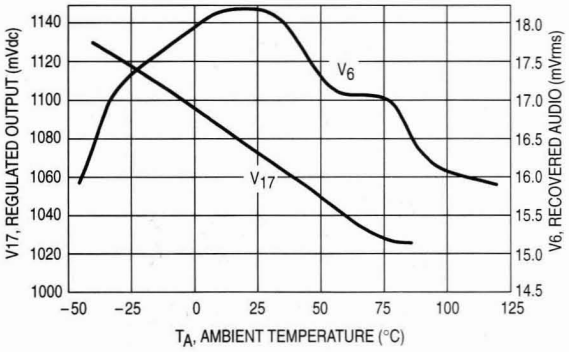



**Figure 6. Buffer Amplifier Gains versus Temperature**

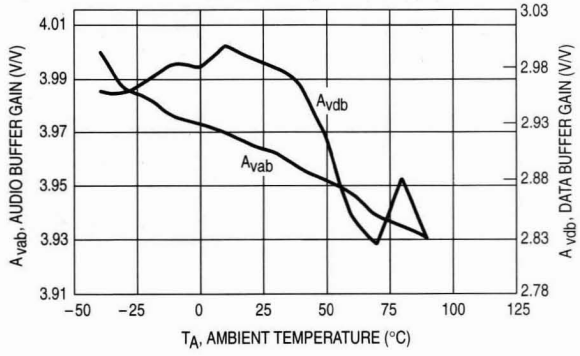



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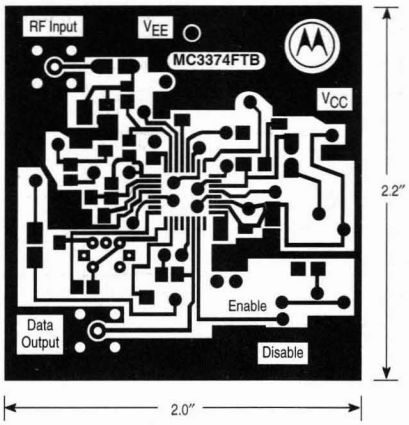
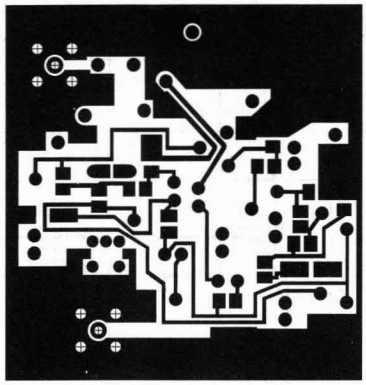
**Figure 7. MC3374 Pager Receiver PCB Artwork**

**COPPER 1 LAYER**
(Actual View of Surface Mount Side)




**COPPER 2 LAYER**
(Caution: Reversed View of Through–Hole Side)



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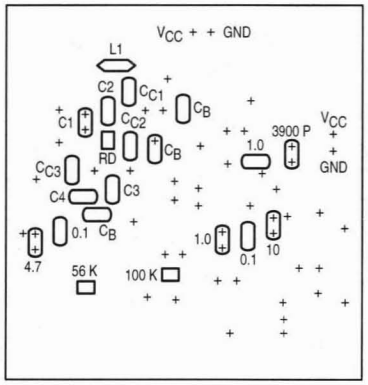
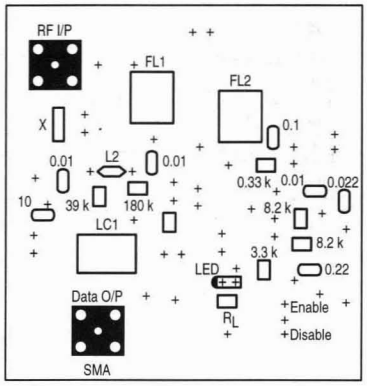
**COMPONENT 1 LAYER**




**COMPONENT 2 LAYER**




**NOTE:** + = Through Hole

## CIRCUIT DESCRIPTION

The MC3374 is an FM narrowband receiver capable of operation to 75 MHz. The low voltage design yields low power drain and excellent sensitivity in narrowband voice and data link applications. In the typical application the mixer amplifies the incoming RF or IF signal and converts this frequency to 455 kHz. The signal is then filtered by a 455 kHz ceramic filter and applied to the first intermediate frequency (IF) amplifier input, before passing through a second ceramic filter. The modulated IF signal is then applied to the limiting IF amplifier and detector circuitry. Modulation is recovered by a conventional quadrature detector. The typical modulation bandwidth available is 3.0 to 5.0 kHz.

Features available include buffers for audio/data amplification and active filtering, on board voltage regulator, low battery detection circuitry with programmable level, and receiver disable circuitry. The MC3374 is an FM utility receiver to be used for voice and/or narrowband data reception. It is especially suitable where extremely low power consumption and high design flexibility are required.

## APPLICATION

The MC3374 can be used as a high performance FM IF for the use in low power dual conversion receivers. Because of the MC3374's extremely good sensitivity (0.6 μV for 20 dB (S+N/N, see Figure 3)), it can also be used as a stand alone single conversion narrowband receiver to 75 MHz for applications not sensitive to image frequency interference. An RF preamplifier will likely be needed to overcome preselector losses.

The oscillator is a Colpitts type which must be run under crystal control. For fundamental mode crystals choose resonators, parallel resonant, for a 32 pF load. For higher frequencies, use a 3rd overtone series mode type. The coil L2 and RD resistor are needed to ensure proper operation.

The best adjacent channel and sensitivity response occur when two 455 kHz ceramic filters are used, as shown in Figure 1. Either can be replaced by a 0.1 μF coupling capacitor to reduce cost, but some degradation in sensitivity and/or stability is suspected.

The detector is a quadrature type, with the connection from the limiter output to the detector input provided internally. A 455 kHz LC tank circuit must be provided externally. One of the tank pins (Pin 8) must be decoupled using a 0.1 μF capacitor. The 56 kΩ damping resistor (see Figure 1), determines the peak separation of the detector (and thus its bandwidth). Smaller values will increase the separation and bandwidth but decrease recovered audio and sensitivity.

The data buffer is a noninverting amplifier with a nominal voltage gain of 2.7 V/V. This buffer needs its dc bias (approximately 250 mV) provided externally or else debiasing will occur. A 2nd order Sallen–Key low pass filter, as shown in Figure 1, connecting the recovered audio output to the data buffer input provides the necessary dc bias and some post detection filtering. The buffer can also be used as an active filter.

The audio buffer is a noninverting amplifier with a nominal voltage gain of 4.0 V/V. This buffer is self–biasing so its input should be ac coupled. The two buffers, when applied as active filters, can be used together to allow simultaneous audio and very low speed data reception. Another possible configuration is to receive audio only and include a noise–triggered squelch.

The comparator is a noninverting type with an open collector output. Typically, the pull–up resistor used between Pin 14 and $V_{CC}$ is 100 kΩ. With $R_L$ = 100 kΩ the comparator is capable of operation up to 25 kHz. The circuit is self–biasing, so its input should be ac coupled.

The regulator is a 1.07 V reference capable of sourcing 3.0 mA. This pin (Pin 17) needs to be decoupled using a 1.0–10 μF capacitor to maintain stability of the MC3374.

All three $V_{CC}$s on the MC3374 ($V_{CC}$, $V_{CC2}$, $V_{CC3}$) run on the same supply voltage. $V_{CC}$ is typically decoupled using capacitors only. $V_{CC2}$ and $V_{CC3}$ should be bypassed using the RC bypasses shown in Figure 1. Eliminating the resistors on the $V_{CC2}$ and $V_{CC3}$ bypasses may be possible in some applications, but a reduction in sensitivity and quieting will likely occur.

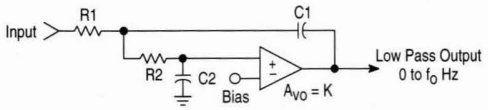
The low battery detection circuit gives an NPN open collector output at Pin 20 which drops low when the MC3374 supply voltage drops below 1.2 V. Typically it would be pulled up via a 100 kΩ resistor to supply.

The 1.2 V Select pin, when connected to the MC3374 supply, programs the low battery detector to trip at $V_{CC}$ < 1.1 V. Leaving this pin open raises the trip voltage on the low battery detector.

Pin 15 is a receiver enable which is connected to $V_{CC}$ for normal operation. Connecting this pin to ground shuts off receiver and reduces current drain to $I_{CC}$ < 0.5 μA.

## APPENDIX

### Design of 2nd Order Sallen–Key Low Pass Filters




The audio and data buffers can easily be configured as active low pass filters using the circuit configuration shown above. The circuit has a center frequency ($f_o$) and quality factor (Q) given by the following:

$$f_o = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

$$Q = \frac{1}{\sqrt{\frac{R2C2}{R1C1}} + \sqrt{\frac{R1C2}{R2C1}} + (1-K)\sqrt{\frac{R1C1}{R2C2}}}$$

If possible, let R1 = R2 or C1 = C2 to simplify the above equations. Be sure to avoid a negative Q value to prevent instability. Setting $Q = 1/\sqrt{2} = 0.707$ yields a maximally flat filter response.

8

### Data Buffer Design

The data buffer is designed as follows:

$f_O$ = 200 Hz
C1 = C2 = 0.01 μF
Q = 0.707 (target)

K = 2.7 (data buffer open loop voltage gain)

Setting C1 = C2 yields:

$$fo = \frac{1}{2\pi C1\sqrt{R1R2}}$$

$$Q = \frac{1}{\sqrt{\frac{R2}{R1}} + (2-K)\sqrt{\frac{R1}{R2}}}$$

Iteration yields R2 = 4.2 (R1) to make Q = 0.707.
Substitution into the equation for $f_O$ yields:
R1 = 38 kΩ (use 39 kΩ)
R2 = 4.2(R1) = 180 kΩ
C1 = C2 = 0.01 μF

### Audio Buffer Design

The audio buffer is designed as follows:

$f_O$ = 3000 Hz
R1 = R2 = 8.2 kΩ
Q = 0.707 (target)

K = 3.9 (audio buffer open loop voltage gain)

Setting C1 = C2 yields:

$$fo = \frac{1}{2\pi R1\sqrt{C1C2}}$$

$$Q = \frac{1}{\sqrt{\frac{C2}{C1}} + (1-K)\sqrt{\frac{C1}{C2}}}$$

Iteration yields C2 = 2.65 (C1) to make Q = 0.707.
Substitution into the equation for $f_O$ yields:
C1 = 3900 pF
C2 = 2.65(C1) = 0.01 μF
R1 = R2 = 8.2 kΩ

8

MOTOROLA

# MC13055

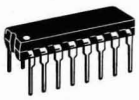
## Wideband FSK Receiver

The MC13055 is intended fo RF data link systems using carrier frequencies up to 40 MHz and FSK (frequency shift keying) data rates up to 2.0 M Baud (1.0 MHz). This design is similar to the MC3356, except that it does not include the oscillator/mixer. The IF bandwidth has been increased and the detector output has been revised to a balanced configuration. The received signal strength metering circuit has been retained, as has the versatile data slicer/comparator.

- Input Sensitivity 20 μV @ 40 MHz
- Signal Strength Indicator Linear Over 3 Decades
- Available in Surface Mount Package
- Easy Application, Few Peripheral Components

**WIDEBAND FSK RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

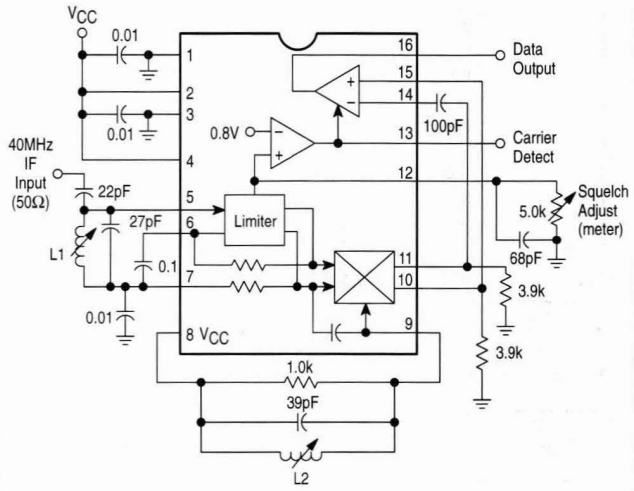


**P SUFFIX**
PLASTIC PACKAGE
CASE 648

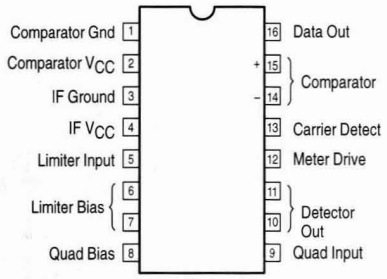
**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

8

**Figure 1. Block Diagram and Application Circuit**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13055D | $T_A$ = – 40 to +85°C | SO–16 |
| MC13055P | | Plastic DIP |

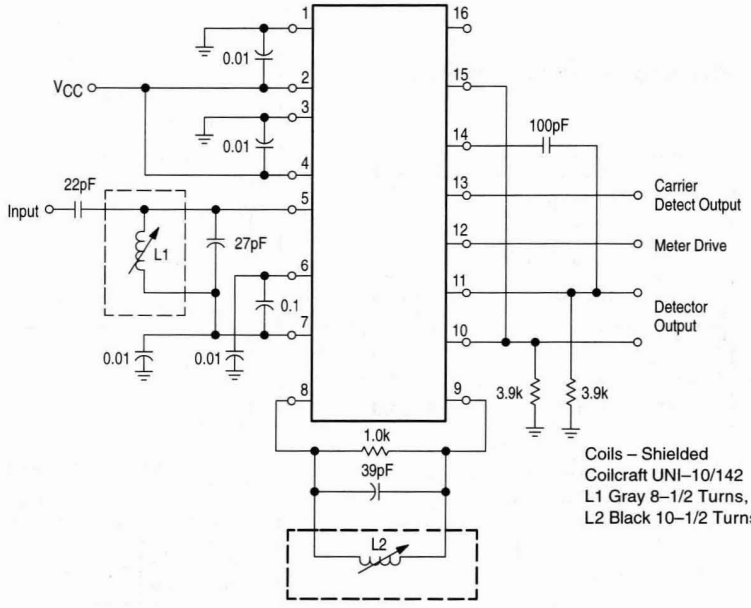
**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC(max)}$ | 15 | Vdc |
| Operating Supply Voltage Range | V2, V4 | 3.0 to 12 | Vdc |
| Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Power Dissipation, Package Rating | $P_D$ | 1.25 | W |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $f_o$ = 40 MHz, $f_{mod}$ = 1.0 MHz, Δf = ±1.0 MHz, $T_A$ = 25°C, test circuit of Figure 2.)

| Characteristic | | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Total Drain Current | | 12 + 14 | – | 20 | 25 | mA |
| Data Comparator Pull–Down Current | | I16 | – | 10 | – | mA |
| Meter Drive Slope versus Input | | I12 | 4.5 | 7.0 | 9.0 | µA/dB |
| Carrier Detect Pull–Down Current | | I13 | – | 1.3 | – | mA |
| Carrier Detect Pull–Up Current | | I13 | – | 500 | – | µA |
| Carrier Detect Threshold Voltage | | V12 | 690 | 800 | 1010 | mV |
| DC Output Current | | I10, I11 | – | 430 | – | µA |
| Recovered Signal | | V10 – V11 | – | 350 | – | mVrms |
| Sensitivity for 20 dB S + N/N, BW = 5.0 MHz | | VIN | – | 20 | – | µVrms |
| S + N/N at $V_{in}$ = 50 µV | | V10 – V11 | – | 30 | – | dB |
| Input Impedance @ 40 MHz | $R_{in}$<br>$C_{in}$ | Pin 5, Ground | –<br>– | 4.2<br>4.5 | –<br>– | kΩ<br>pF |
| Quadrature Coil Loading | $R_{in}$<br>$C_{in}$ | Pin 9 to 8 | –<br>– | 7.6<br>5.2 | –<br>– | kΩ<br>pF |

**Figure 2. Test Circuit**




Coils – Shielded
Coilcraft UNI–10/142
L1 Gray 8–1/2 Turns, nominal 300 nH
L2 Black 10–1/2 Turns, nominal 380 nH

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**Figure 3. Overall Gain, Noise, AM Rejection**

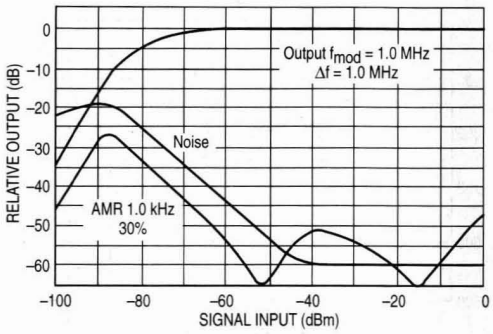


**Figure 4. Meter Current versus Signal**

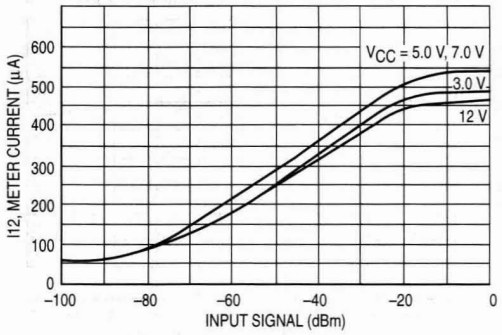


**Figure 5. Untuned Input: Limiting Sensitivity versus Frequency**

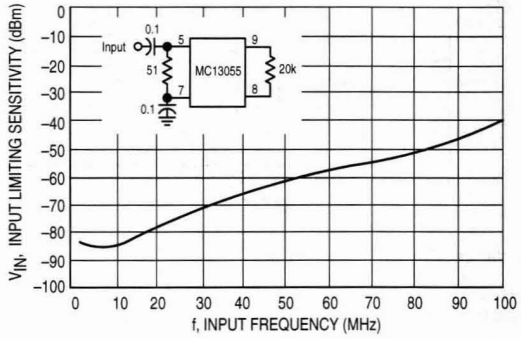


**Figure 6. Untuned Input: Meter Current versus Frequency**

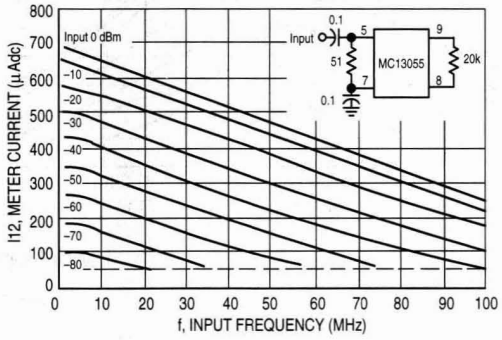


**Figure 7. Limiting Sensitivity and Detuning versus Supply Voltage**

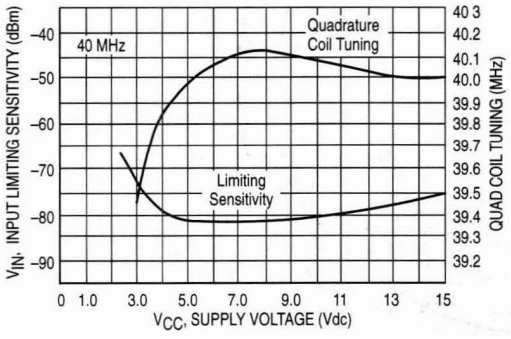


**Figure 8. Detector Current and Power Supply Current versus Supply Voltage**

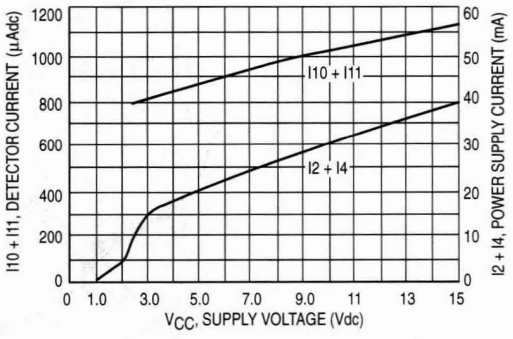


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**Figure 9. Recovered Audio versus Temperature**

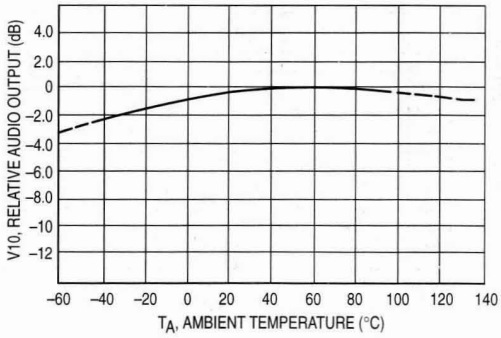


**Figure 10. Carrier Detect Threshold versus Temperature**

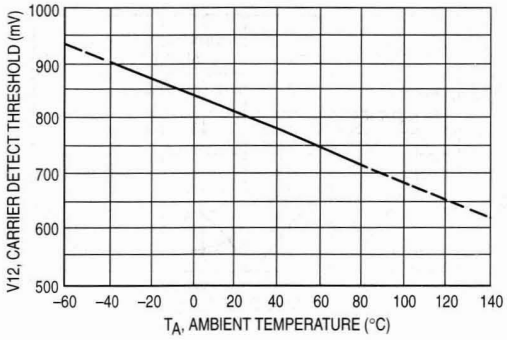


**Figure 11. Meter Current versus Temperature**

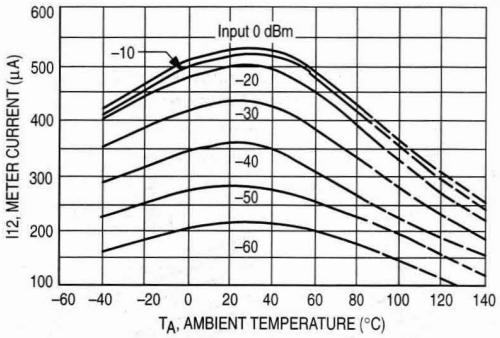


**Figure 12. Input Limiting versus Temperature**

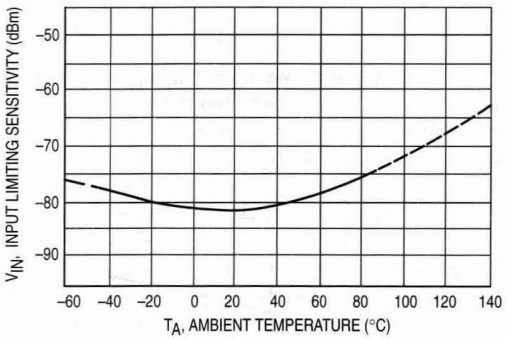


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**Figure 13. Input Impedance, Pin 5**

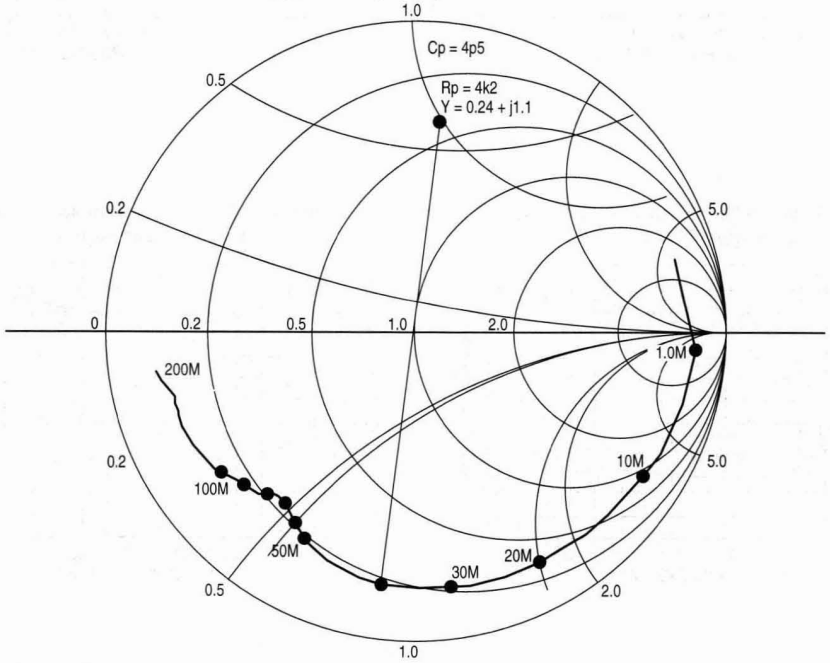
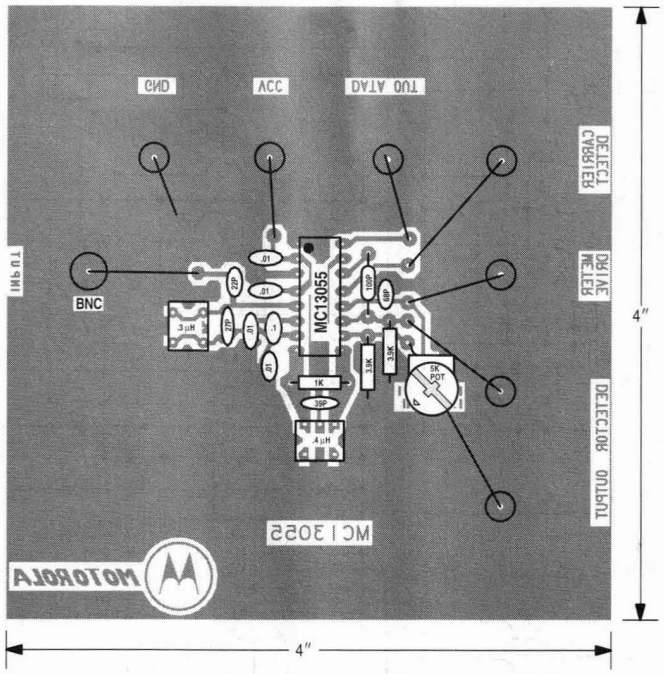


Figure 14. Test Fixture
(Component Layout)




(Circuit Side View)

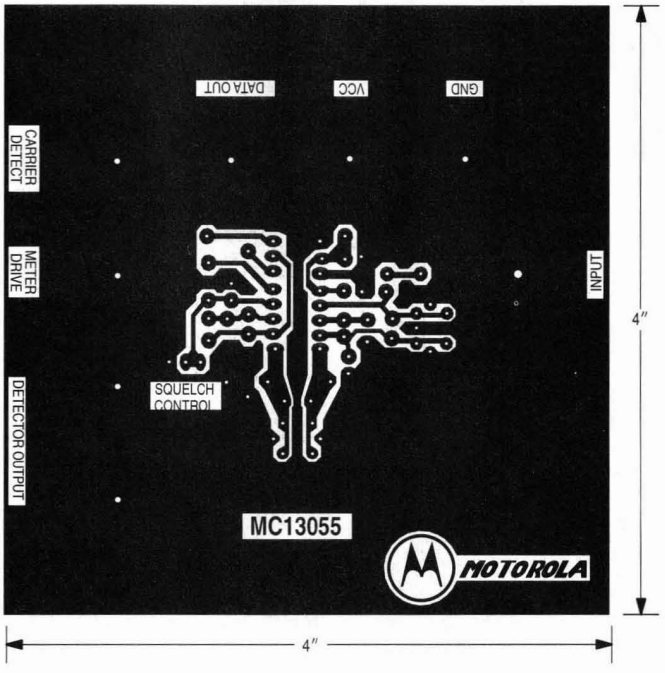



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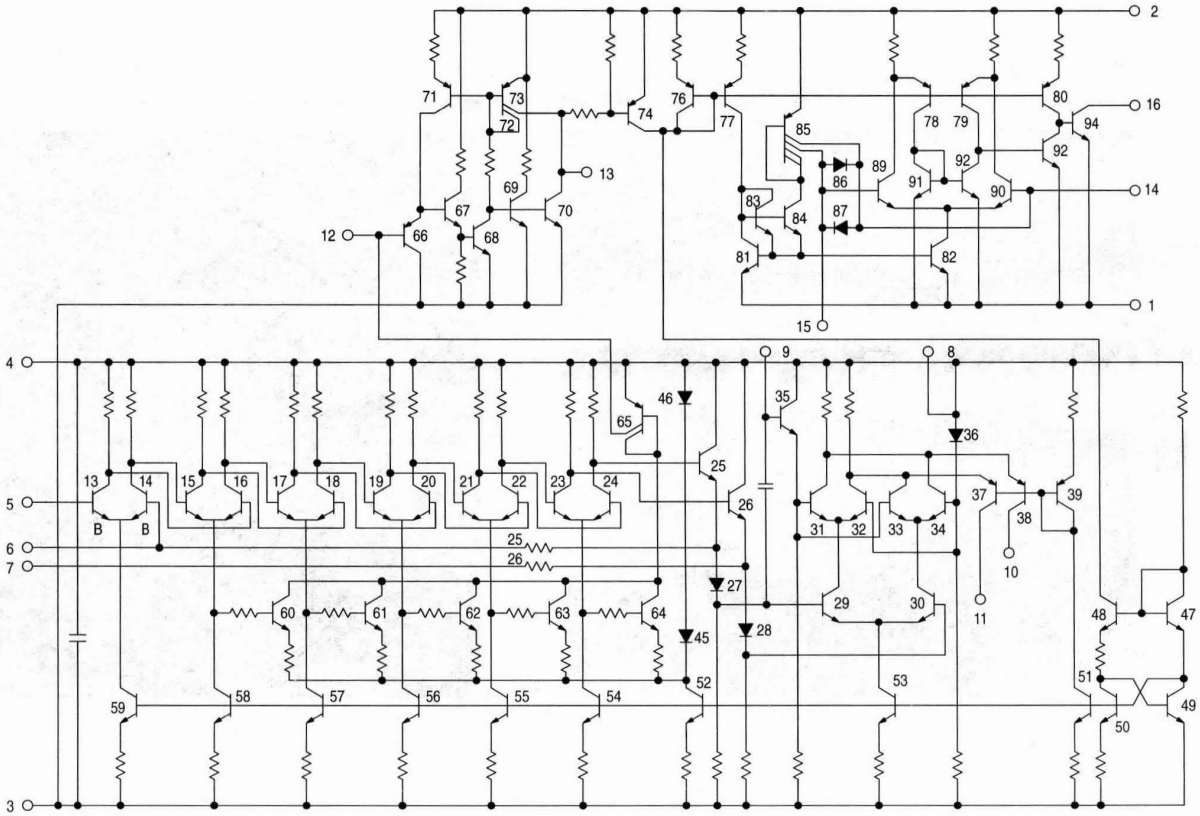
**Figure 15. Internal Schematic**



## GENERAL DESCRIPTION

The MC13055 is an extended frequency range FM IF, quadrature detector, signal strength detector and data shaper. It is intended primarily for FSK data systems. The design is very similar to MC3356 except that the oscillator/mixer has been removed, and the frequency capability of the IF has been raised about 2:1. The detector output configuration has been changed to a balanced, open–collector type to permit symmetrical drive of the data shaper (comparator). Meter drive and squelch features have been retained.

The limiting IF is a high frequency type, capable of being operated up to 100 MHz. It is expected to be used at 40 MHz in most cases. The quadrature detector is internally coupled to the IF, and a 2.0 pF quadrature capacitor is internally provided. The 20 dB quieting sensitivity is approximately 20 μV, tuned input, and the IF can accept signals up to 220 mVrms without distortion or change of detector quiescent DC level.

The IF is unusual in that each of the last 5 stages of the 6 stage limiter contains a signal strength sensitive, current sinking device. These are parallel connected and buffered to produce a signal strength meter drive which is fairly linear for IF input signals of 20 μV to 20 mVrms (see Figure 4).

A simple squelch arrangement is provided whereby the meter current flowing through the meter load resistance flips a comparator at about 0.8 Vdc above ground. The signal strength at which this occurs can be adjusted by changing the meter load resistor. The comparator (+) input and output are available to permit control of hysteresis. Good positive action can be obtained for IF input signals of above 20 μVrms. A resistor (R) from Pin 13 to Pin 12 will provide $V_{CC}/R$ of feedback current. This current can be correlated to an amount of signal strength hysteresis by using Figure 4.

The squelch is internally connected to the data shaper. Squelch causes the data shaper to produce a high ($V_{CC}$) output.

The data shaper is a complete "floating" comparator, with diodes across its inputs. The outputs of the quadrature detector can be fed directly to either or preferably both inputs of the comparator to produce a squared output swinging from $V_{CC}$ to ground in inverted or noninverted form.

MOTOROLA

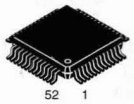
# MC13109

# Universal Cordless Telephone Subsystem IC

**UNIVERSAL CT–1 SUBSYSTEM INTEGRATED CIRCUIT**

The MC13109 integrates several of the functions required for a cordless telephone into a single integrated circuit. This significantly reduces component count, board space requirements, and external adjustments. It is designed for use in both the handset and the base.

- Dual Conversion FM Receiver
  - Complete Dual Conversion Receiver – Antenna Input to Audio Output 80 MHz Maximum Carrier Frequency
  - RSSI Output
  - Carrier Detect Output with Programmable Threshold
  - Comparator for Data Recovery
  - Operates with Either a Quad Coil or Ceramic Discriminator
- Compander
  - Expandor Includes Mute, Digital Volume Control and Speaker Driver
  - Compressor Includes Mute, ALC and Limiter
- Dual Universal Programmable PLL
  - Supports New 25 Channel U.S. Standard with No External Switches
  - Universal Design for Domestic and Foreign CT–1 Standards
  - Digitally Controlled Via a Serial Interface Port
  - Receive Side Includes 1st LO VCO, Phase Detector, and 14–Bit Programmable Counter and 2nd LO with 12–Bit Counter
  - Transmit Section Contains Phase Detector and 14–Bit Counter
  - MPU Clock Output Eliminates Need for MPU Crystal
- Supply Voltage Monitor
  - Externally Adjustable Trip Point
- 2.0 to 5.5 V Operation with One–Third the Power Consumption of Competing Devices
- AN1575: Refer to Application Note for a List of "Worldwide Cordless Telephone Frequencies" (Chapter 8 Addendum of DL128 Data Book)



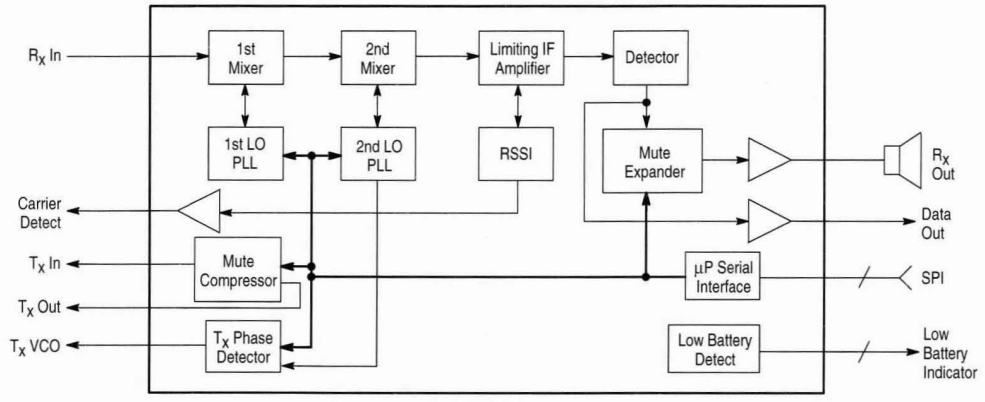

**FB SUFFIX**
PLASTIC PACKAGE
CASE 848B
(QFP–52)

**FTA SUFFIX**
PLASTIC PACKAGE
CASE 932
(Thin QFP)

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC13109FB | $T_A$ = –20° to +85°C | QFP–52 |
| MC13109FTA | | TQFP–48 |

**Simplified Block Diagram**




This device contains 6,609 active transistors.

**Figure 1. MC13109FB Test Circuit**

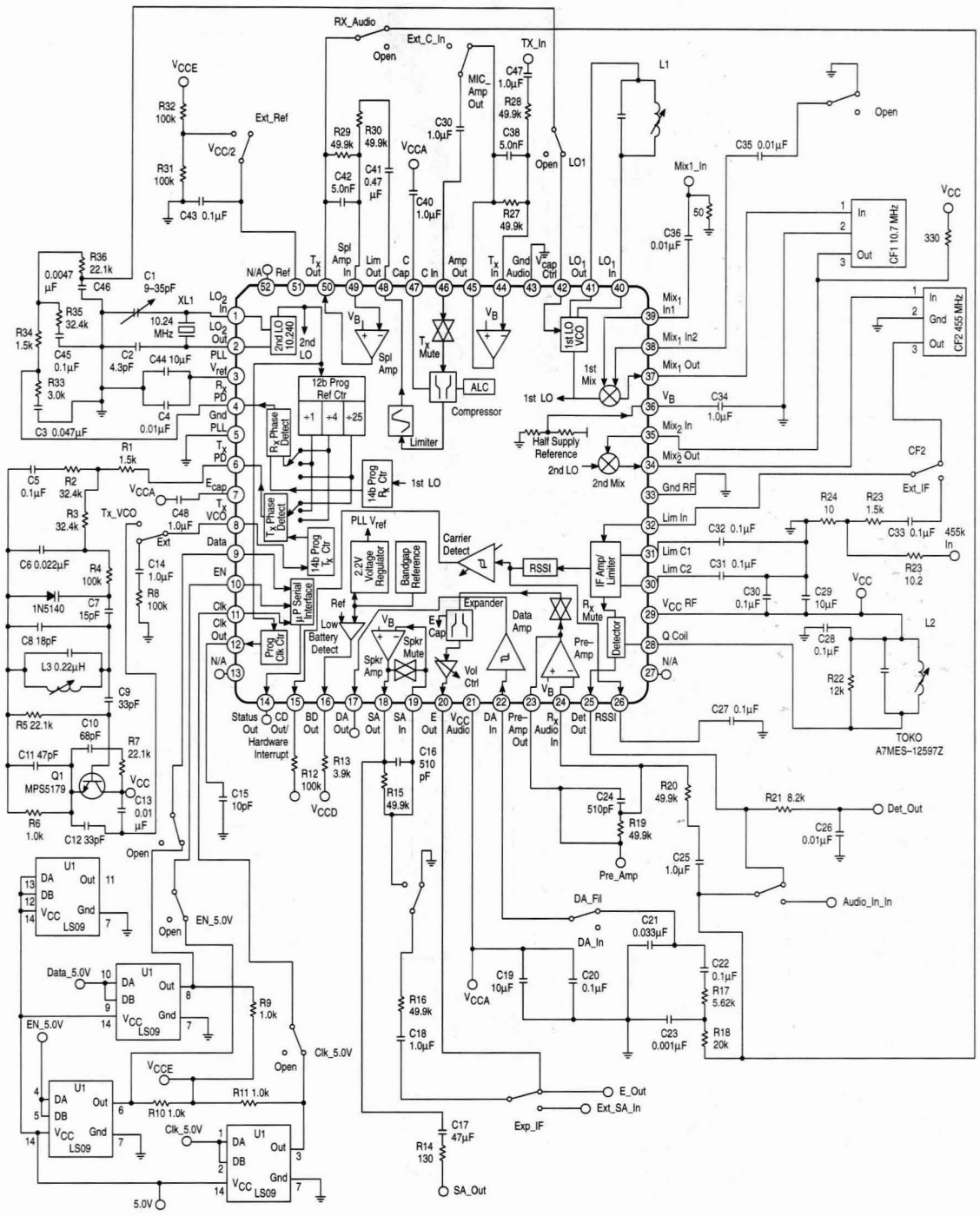
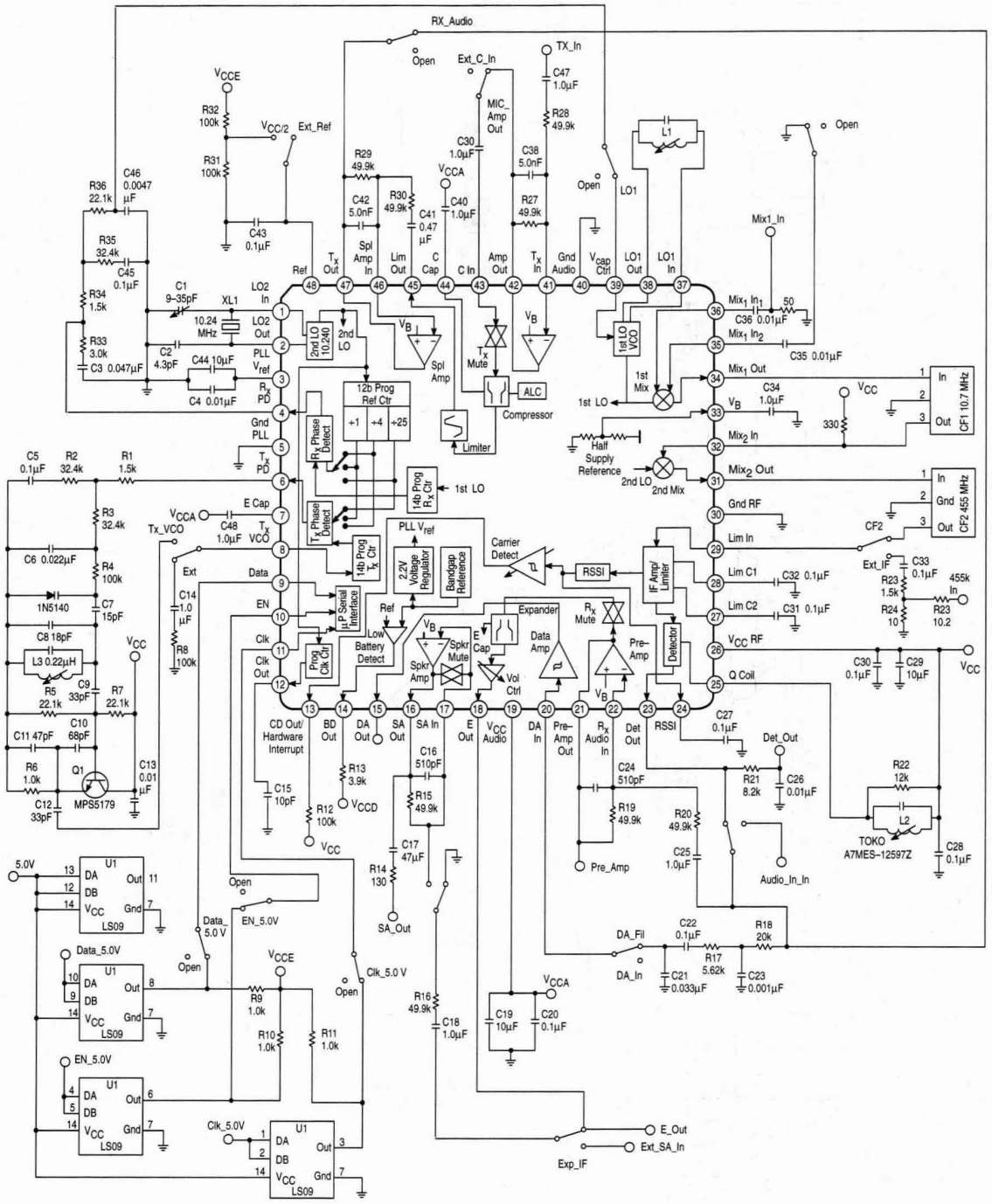


**Figure 2. MC13109FTA Test Circuit**



## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | −0.5 to +5.5 | Vdc |
| Junction Temperature | $T_J$ | −65 to +150 | °C |

**NOTE:** 1. Devices should not be operated at these limits. The "Recommended Operating Conditions" provide for actual device operation.
2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| $V_{CC}$ | 2.0 | – | 5.5 | Vdc |
| Operating Ambient Temperature | –20 | – | 85 | °C |

**NOTE**: All limits are not necessarily functional concurrently.

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 2.6 V, $T_A$ = 25°C, RF In = 46.61 MHz, $f_{DEV}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz; Test Circuit Figure 1.)

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **POWER SUPPLY** | | | | |
| Static Current | | | | |
| Active Mode ($V_{CC}$ = 2.6 V) | – | 6.7 | 12 | mA |
| Active Mode ($V_{CC}$ = 3.6 V) | – | 7.1 | – | mA |
| Receive Mode ($V_{CC}$ = 2.6 V) | – | 4.3 | 7.0 | mA |
| Receive Mode ($V_{CC}$ = 3.6 V) | – | 4.5 | – | mA |
| Standby Mode ($V_{CC}$ = 2.6 V) | – | 300 | 600 | µA |
| Standby Mode ($V_{CC}$ = 3.6 V) | – | 600 | – | µA |
| Inactive Mode ($V_{CC}$ = 2.6 V) | – | 40 | 80 | µA |
| Inactive Mode ($V_{CC}$ = 3.6 V) | – | 56 | – | µA |

8

**ELECTRICAL CHARACTERISTICS (continued)**

**FM Receiver**

The FM receivers can be used with either a quad coil or a ceramic resonator. The FM receiver and 1st LO have been designed to work for all country channels, including 25 channel U.S., without the need for any external switching circuitry (see Figure 29).

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C, $f_O$ = 46.61 MHz, $f_{DEV}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Sensitivity (Input for 12 dB SINAD) | Matched Impedance Differential Input | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | – | 0.7 | – | µVrms |
| 1st Mixer Conversion Gain | $V_{in}$ = 1.0 mVrms, with $CF_1$ Load | $Mix_1$ $In_{1/2}$ | $CF_1$ | $MX_{gain1}$ | – | 10 | – | dB |
| 2nd Mixer Conversion Gain | $V_{in}$ = 3.0 mVrms, with $CF_2$ Load | $Mix_2$ In | $CF_2$ | $MX_{gain2}$ | – | 20 | – | dB |
| 1st and 2nd Mixer Gain Total | $V_{in}$ = 1.0 mVrms, with $CF_1$ and $CF_2$ Load | $Mix_1$ $In_{1/2}$ | $CF_2$ | $MX_{gainT}$ | 24 | 30 | – | dB |
| 1st Mixer Input Impedance | – | – | $Mix_1$ $In_1$ $Mix_1$ $In_2$ | $Z_{in1}$ | – | 1.0 | – | kΩ |
| 2nd Mixer Input Impedance | – | – | $Mix_2$ In | $Z_{in2}$ | – | 3.0 | – | kΩ |
| 1st Mixer Output Impedance | – | – | $Mix_1$ Out | $Z_{out1}$ | – | 330 | – | Ω |
| 2nd Mixer Output Impedance | – | – | $Mix_2$ Out | $Z_{out2}$ | – | 1.5 | – | kΩ |
| IF –3.0 dB Limiting Sensitivity | $f_{in}$ = 455 kHz | Lim In | Det Out | IF Sens | – | 55 | – | µVrms |
| Total Harmonic Distortion (CCITT Filter) | With $R_C$ = 8.2 kΩ/ 0.01 µF Filter at Det Out | $Mix_1$ $In_{1/2}$ | Det Out | THD | – | 0.7 | – | % |
| Recovered Audio | With $R_C$ = 8.2 kΩ/ 0.01 µF Filter at Det Out | $Mix_1$ $In_{1/2}$ | Det Out | AFO | 80 | 100 | 154 | mVrms |
| Demodulator Bandwidth | – | Lim In | Det Out | BW | – | 20 | – | kHz |
| Signal to Noise Ratio | $V_{in}$ = 10 mVrms, $R_C$ = 8.2 kΩ/0.01 µF | $Mix_1$ $In_{1/2}$ | Det Out | SN | – | 49 | – | dB |
| AM Rejection Ratio | 30% AM, $V_{in}$ = 10 mVrms, $R_C$ = 8.2 kΩ/0.001 µF | $Mix_1$ $In_{1/2}$ | Det Out | AMR | – | 37 | – | dB |
| First Mixer 3rd Order Intercept (Input Referred) | Matched Impedance Input | $Mix_1$ $In_{1/2}$ | $Mix_1$ Out | $TOI_{mix1}$ | – | –10 | – | dBm |
| Second Mixer 3rd Order Intercept (Input Referred) | Matched Impedance Input | $Mix_2$ In | $Mix_2$ Out | $TOI_{mix2}$ | – | –27 | – | dBm |
| Detector Output Impedance | – | – | Det Out | $Z_O$ | – | 870 | – | Ω |

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**ELECTRICAL CHARACTERISTICS (continued)**

**RSSI/Carrier Detect**

Connect 0.01 µF to Gnd from "RSSI" output pin to form the carrier detect filter. "CD Out" is an open collector output which requires an external 100 kΩ pull–up resistor to $V_{CC}$. The carrier detect threshold is programmable through the MPU interface.

($R_L$ = 100 kΩ, $V_{CC}$ = 2.6 V, $T_A$ = 25°C.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| RSSI Output Current Dynamic Range | – | $Mix_1$ In | RSSI | RSSI | – | 65 | – | dB |
| Carrier Sense Threshold | CD Threshold Adjust = (10100) | $Mix_1$ In | CD Out | $V_T$ | – | 22.5 | – | µVrms |
| Hysteresis | – | Mix1 In | CD Out | Hys | – | 2.0 | – | dB |
| Output High Voltage | $V_{in}$ = 0 µVrms, $R_L$ = 100 kΩ, CD = (10100) | $Mix_1$ In | CD Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 2.6 | – | V |
| Output Low Voltage | $V_{in}$ = 100 µVrms, $R_L$ = 100 kΩ, CD = (10100) | $Mix_1$ In | CD Out | $V_{OL}$ | – | 0.01 | 0.4 | V |
| Carrier Sense Threshold Adjustment Range | Programmable through MPU Interface | – | – | $V_{Trange}$ | –20 | – | 11 | dB |
| Carrier Sense Threshold – Number of Steps | Programmable through MPU Interface | – | – | $V_{Tn}$ | – | 32 | – | – |

**Data Amp Comparator** (see Figure 4)

Inverting hysteresis comparator. Open collector output with internal 100 kΩ pull–up resistor. A band pass filter is connected between the "Det Out" pin and the "DA In" pin with component values as shown in the attached block diagram. The "DA In" input signal is ac coupled.

($V_{CC}$ = 2.6 V, $T_A$ = 25°C)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Hysteresis | – | DA In | DA Out | Hys | 30 | 40 | 50 | mV |
| Threshold Voltage | – | DA In | DA Out | $V_T$ | $V_{CC}$ – 0.9 | $V_{CC}$ – 0.7 | $V_{CC}$ – 0.5 | V |
| Input Impedance | – | – | DA In | $Z_I$ | – | 11 | – | kΩ |
| Output Impedance | – | – | DA Out | $Z_O$ | – | 100 | – | kΩ |
| Output High Voltage | $V_{in}$ = $V_{CC}$ – 1.0 V, $I_{OH}$ = 0 mA | DA In | DA Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 2.6 | – | V |
| Output Low Voltage | $V_{in}$ = $V_{CC}$ – 0.4 V, $I_{OL}$ = 0 mA | DA In | DA Out | $V_{OL}$ | – | 0.03 | 0.4 | V |

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**ELECTRICAL CHARACTERISTICS (continued)**

**Pre–Amplifier/Expander/$R_X$ Mute/Volume Control** (See Figure 4)

The Pre–Amplifier is an inverting rail–to–rail output swing operational amplifier with the non–inverting input terminal connected to the internal $V_B$ half supply reference. External resistors and capacitors can be connected to set the gain and frequency response. The expander analog ground is set to the half supply reference so the input and output swing capability will increase as the supply voltage increases. The volume control can be adjusted through the MPU interface. The "$R_X$ Audio In" input signal is ac coupled.

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C, $f_{in}$ = 1.0 kHz, Set External Pre–Amplifier R's for Gain of 1, Volume Control = (0111).)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Pre–Amp Open Loop Gain | – | $R_X$ Audio In | Pre–Amp | $A_{VOL}$ | – | 60 | – | dB |
| Pre–Amp Gain Bandwidth | – | $R_X$ Audio In | Pre–Amp | GBW | – | 100 | – | kHz |
| Pre–Amp Maximum Output Swing | $R_L$ = 10 kΩ | $R_X$ Audio In | Pre–Amp | $V_{Omax}$ | – | $V_{CC}$ – 0.3 | – | $V_{pp}$ |
| Expander 0 dB Gain Level | $V_{in}$ = –10 dBV | $R_X$ Audio In | E Out | G | –3.0 | –0.11 | 3.0 | dB |
| Expander Gain Tracking | $V_{in}$ = –20 dBV, Output Relative to G<br>$V_{in}$ = –30 dBV, Output Relative to G | $R_X$ Audio In | E Out | $G_t$ | –21<br>–42 | –19.65<br>–39.42 | –19<br>–37 | dB |
| Total Harmonic Distortion | $V_{in}$ = –10 dBV | $R_X$ Audio In | E Out | THD | – | 0.5 | – | % |
| Maximum Output Voltage | Increase input voltage until output voltage THD = 5%, then measure output voltage. $R_L$ = 10 kΩ | $R_X$ Audio In | E Out | $V_{Omax}$ | – | –5.0 | – | dBV |
| Attack Time | $E_{cap}$ = 1.0 μF, $R_{filt}$ = 20 kΩ (See Appendix B) | $R_X$ Audio In | E Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $E_{cap}$ = 1.0 μF, $R_{filt}$ = 20 kΩ (See Appendix B) | $R_X$ Audio In | E Out | $t_r$ | – | 13.5 | – | ms |
| Compressor to Expander Crosstalk | V ($R_X$ Audio In) = 0 Vrms, $V_{in}$ = –10 dBV | C In | E Out | $C_T$ | – | – | –70 | dB |
| $R_X$ Mute | $V_{in}$ = –10 dBV No popping detectable during $R_X$ Mute transitions | $R_X$ Audio In | E Out | $M_e$ | – | –70 | – | dB |
| Volume Control Range | Programmable through MPU Interface | – | – | $V_{Crange}$ | –14 | – | 16 | dB |
| Volume Control Steps | Programmable through MPU Interface | – | – | $V_{Cn}$ | – | 16 | – | – |

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**ELECTRICAL CHARACTERISTICS (continued)**

**Speaker Amplifier/SP Mute**

The Speaker Amplifier is an inverting rail–to–rail operational amplifier. The non–inverting input terminal is connected to the internal $V_B$ half supply reference. External resistors and capacitors are used to set the gain and frequency response. The "SA In" input is ac coupled.

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C, $f_{in}$ = 1.0 kHz, External Resistors Set for Gain of 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Maximum Output Swing | $V_{CC}$ = 2.3 V, $R_L$ = 130 Ω | SA In | SA Out | $V_{Omax}$ | – | 0.8 | – | $V_{pp}$ |
| | $V_{CC}$ = 2.3 V, $R_L$ = 600 Ω | | | | – | 2.0 | – | |
| | $V_{CC}$ = 3.4 V, $R_L$ = 600 Ω | | | | – | 3.0 | – | |
| SP Mute | $V_{in}$ = –20 dBV $R_L$ = 130 Ω No popping detectable during SP Mute transitions | SA In | SA Out | $M_{sp}$ | – | –70 | – | dB |

**Mic Amplifier** (See Figure 6)

The Mic Amplifier is an inverting rail–to–rail output operational amplifier with the non–inverting input terminal connected to the internal $V_B$ half supply reference. External resistors and capacitors are connected to set the gain and frequency response. The "$T_X$ In" input is ac coupled.

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C, $f_{in}$ = 1.0 kHz, External Resistors Set for Gain of 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Open Loop Gain | – | $T_X$ In | Amp Out | $A_{VOL}$ | – | 60 | – | dB |
| Gain Bandwidth | – | $T_X$ In | Amp Out | $G_{BW}$ | – | 100 | – | kHz |
| Maximum Output Swing | $R_L$ = 10 kΩ | $T_X$ In | Amp Out | $V_{Omax}$ | – | $V_{CC}$ – 0.3 | – | $V_{pp}$ |

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**ELECTRICAL CHARACTERISTICS (continued)**

**Compressor/ALC/$T_X$ Mute/Limiter** (See Figure 5)

The compressor analog gound is set to the half supply reference so the input and output swing capability will increase as the supply voltage increases. The "C In" input is ac coupled. The ALC (Automatic Level Control) provides a soft limit to the output signal swing as the input voltage increases slowly (i.e., a sine wave is maintained). The Limiter circuit limits rapidly changing signal levels by clipping the signal peaks. The ALC and/or Limiter can be disabled through the MPU serial interface.

(Test Conditions: $V_{CC}$ = 2.6 V, $f_{in}$ = 1.0 kHz, $T_A$ = 25°C.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Compressor 0 dB Gain Level | $V_{in}$ = –10 dBV, ALC disabled, Limiter disabled | C In | Lim Out | G | –3.0 | –0.17 | 3.0 | dB |
| Compressor Gain Tracking | $V_{in}$ = –30 dBV, Output Relative to G<br>$V_{in}$ = –50 dBV, Output Relative to G | C In | Lim Out | $G_t$ | –11<br>–23 | –10.23<br>–20.23 | –9.0<br>–17 | dB |
| Maximum Compressor Gain | $V_{in}$ –70 dBV | C In | Lim Out | $A_{Vmax}$ | – | 30 | – | dB |
| Total Harmonic Distortion | $V_{in}$ –10 dBV, ALC disabled, Limiter disabled | C In | Lim Out | THD | – | 0.5 | – | % |
| Input Impedance | – | C In | Lim Out | $Z_{in}$ | – | 16 | – | kΩ |
| Attack Time | $C_{cap}$ = 1.0 µF, $R_{filt}$ = 20 kΩ (see Appendix B) | C In | Lim Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $C_{cap}$ = 1.0 µF, $R_{filt}$ = 20 kΩ (see Appendix B) | C In | Lim Out | $t_r$ | – | 13.5 | – | ms |
| Expander to Compressor Crosstalk | V (C In) = 0 Vrms, $V_{in}$ = –10 dBV | $R_X$ Audio In | Lim Out | $C_T$ | – | – | –40 | dB |
| $T_X$ Data Mute | $V_{in}$ = –10 dBV, ALC disabled No popping detectable during $R_X$ Mute transitions | C In | Lim Out | $M_e$ | – | –70 | – | dB |
| ALC Dynamic Range | – | C In | Lim Out | DR | –24 | – | –2.5 | dBV |
| ALC Output Level | $V_{in}$ = –18 dBV<br>$V_{in}$ = –2.5 dBV | C In | Lim Out | $ALC_{out}$ | –<br>– | –16<br>–12 | –<br>– | dBV |
| Limiter Output Level | ALC disabled | C In | $T_X$ Out | $V_{lim}$ | – | 0.8 | – | $V_{pp}$ |

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**ELECTRICAL CHARACTERISTICS (continued)**

**Splatter Amplifier** (see Figure 7)

The Splatter Amplifier is an inverting rail–to–rail output operational amplifier with the non–inverting input terminal connected to the internal $V_B$ half supply reference. External resistors and capacitors can be connected to set the gain and frequency response. The "Spl Amp In" input is ac coupled.

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C, $f_{in}$ = 1.0 kHz, External resistors Set for Gain of 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Open Loop Gain | – | Spl Amp In | $T_X$ Out | $A_{VOL}$ | – | 60 | – | dB |
| Gain Bandwidth | – | Spl Amp In | $T_X$ Out | GBW | – | 100 | – | kHz |
| Maximum Output Swing | $R_L$ = 10 kΩ | Spl Amp In | $T_X$ Out | $V_{Omax}$ | – | $V_{CC}$ – 0.3 | – | $V_{pp}$ |

**$T_X$ Audio Path Recommendation**

The recommended configuration for the $T_X$ Audio path includes setting the Microphone Amplifier gain to 16 dB using the external gain setting resistors and setting the Splatter Amplifier gain to 9.0 dB using the external gain setting resistors. With these gain values, the total $T_X$ Path transfer characteristic is shown in Figure 7.

**PLL Voltage Regulator**

The PLL supply voltage is regulated to a nominal of 2.2 V. The "$V_{CC}$ Audio" pin is the supply voltage for the internal voltage regulator. The "PLL $V_{ref}$" pin is the 2.2 V regulated output voltage. Two capacitors with 10 µF and 0.01 µF values must be connected to the "PLL $V_{ref}$" pin to filter and stabilize this regulated voltage. The voltage regulator provides power for the 2nd LO, $R_X$ and $T_X$ PLL's, and MPU Interface. The voltage regulator can also be used to provide a regulated supply voltage for external IC's. $R_X$ and $T_X$ PLL loop performance are independent of the power supply voltage when the voltage regulator is used. The voltage regulator requires about 200 mV of "headroom". When the power supply decreases to within about 200 mV of the output voltage, the regulator will go out of regulation but the output voltage will not turn off. Instead, the output voltage will maintain about a 200 mV delta to the power supply voltage as the power supply voltage continues to decrease. The "PLL $V_{ref}$" pin can be connected to "$V_{CC}$ Audio" by the external wiring if voltage higher than 2.2 V is required. But it should not be connected to other supply except "$V_{CC}$ Audio". The voltage regulator is "on" in the Active and $R_X$ modes. In the Standby and Inactive modes, the voltage regulator is turned off to reduce current drain and the "PLL $V_{ref}$" pin is internally connected to "$V_{CC}$ Audio" (i.e., the supply voltage is maintained but is now unregulated).

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Output Voltge Level | $V_{CC}$ = 2.6 V, $O_L$ = 0 mA | – | $V_{CC}$ PLL | $V_{out}$ | 1.9 | 2.2 | 2.5 | V |
| Line Regulation | $I_L$ = 0 mA, $V_{CC}$ = 2.6 to 5.5 V | $V_{CC}$ | $V_{CC}$ PLL | $Reg_{line}$ | – | 1.43 | 40 | mV |
| Load Regulation | $V_{CC}$ = 2.6 V, $I_L$ = 0 to 1.0 mA | $V_{CC}$ | $V_{CC}$ PLL | $Reg_{load}$ | – | –1.86 | 40 | mV |
| Drop–Out Voltage | $I_L$ = 0 mA | – | – | DO | – | – | $V_{out}$ + 200 | mV |

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**ELECTRICAL CHARACTERISTICS (continued)**

**Low Battery Detect**

An external resistor divider is connected to the "Ref" input pin to set the threshold for the low battery detect. The voltage at the "Ref" input pin is compared to an internal 1.23 V Bandgap reference voltage. The "BD Out" pin is open collector and requires and external pull–up resistor to $V_{CC}$.

(Test Conditions: $V_{CC}$ = 2.6 V, $T_A$ = 25°C.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Average Threshold Voltage | Take average of rising and falling threshold | Ref | Ref/ BD Out | Threshold | – | 1.23 | – | V |
| Hysteresis | – | Ref | Ref/ BD Out | Hys | – | 4.0 | – | mV |
| Input Current | $V_{in}$ = 1.6 V | – | Ref | $I_{in}$ | –50 | 5.71 | +50 | nA |
| Output High Voltage | $V_{ref}$ = 1.6, $R_L$ = 3.9 kΩ | Ref | BD Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 2.6 | – | V |
| Output Low Voltage | $V_{ref}$ = 0.9, $R_L$ = 3.9 kΩ | Ref | BD Out | $V_{OL}$ | – | 0.12 | 0.4 | V |

**Figure 3. Data Amp Operation**

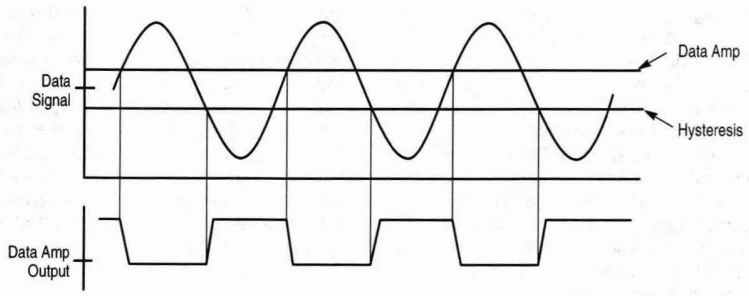



**Figure 4. Typical Expander Response**

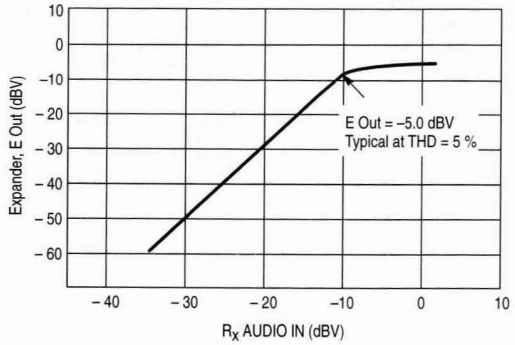


**Figure 5. Typical Compressor/ALC/Limiter Response**

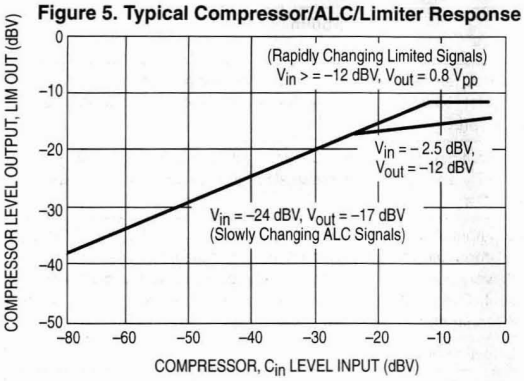

(Rapidly Changing Limited Signals)
$V_{in}$ > = −12 dBV, $V_{out}$ = 0.8 $V_{pp}$
$V_{in}$ = − 2.5 dBV,
$V_{out}$ = −12 dBV
$V_{in}$ = −24 dBV, $V_{out}$ = −17 dBV
(Slowly Changing ALC Signals)
COMPRESSOR LEVEL OUTPUT, LIM OUT (dBV)
COMPRESSOR, $C_{in}$ LEVEL INPUT (dBV)

**Figure 6. Total $T_X$ Path, Mic Amp Gain = 16 dB, Splatter Amp Gain = 9.0 dB**

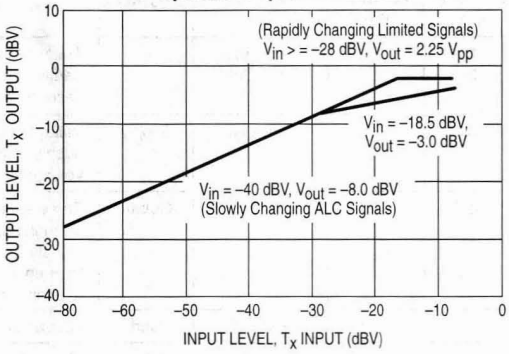
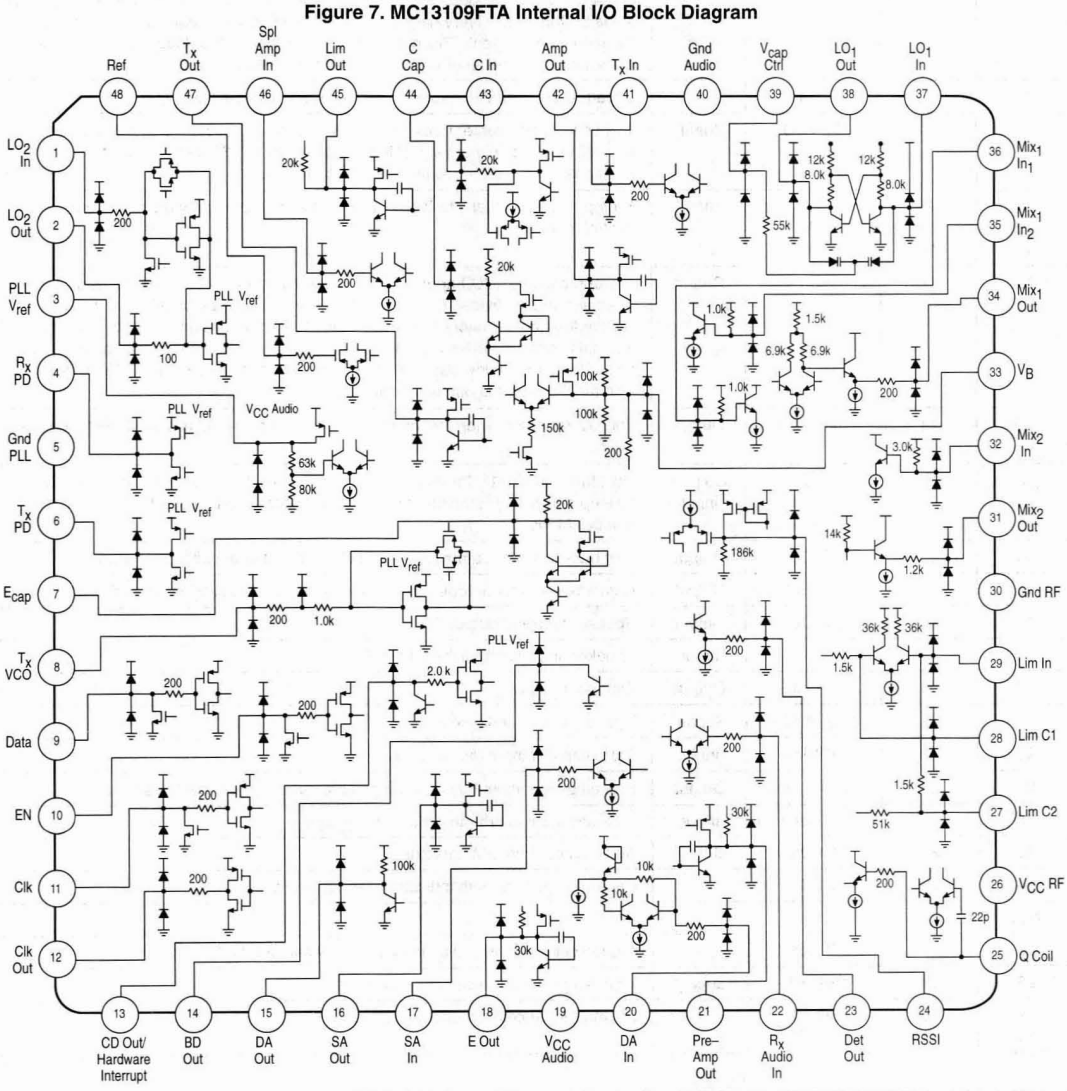

(Rapidly Changing Limited Signals)
$V_{in}$ > = −28 dBV, $V_{out}$ = 2.25 $V_{pp}$
$V_{in}$ = −18.5 dBV,
$V_{out}$ = −3.0 dBV
$V_{in}$ = −40 dBV, $V_{out}$ = −8.0 dBV
(Slowly Changing ALC Signals)
OUTPUT LEVEL, $T_X$ OUTPUT (dBV)
INPUT LEVEL, $T_X$ INPUT (dBV)

**Figure 7. MC13109FTA Internal I/O Block Diagram**



## PIN FUNCTION DESCRIPTION

| 48–TQFP Pin | 52–QFP Pin | Symbol | Type | Description |
|---|---|---|---|---|
| 1<br>2 | 1<br>2 | $LO_2$ In<br>LO2 Out | – | These pins form the PLL reference oscillator when connected to an external parallel–resonant crystal (10.24 MHz typical). The reference oscillator is also the second Local Oscillator ($LO_2$) for the RF receiver. |
| 3 | 3 | PLL $V_{ref}$ | Supply | Voltage Regulator output pin. The internal voltage regulator provides a stable power supply voltage for the $R_X$ and $T_X$ PLL's and can also be used as a regulated supply voltage for the other IC's. |
| 4 | 4 | $R_X$ PD | Output | Three state voltage output of the $R_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $R_X$ PLL loop filter. It is important to minimize the line length and capacitance of this pin. |
| 5 | 5 | Gnd PLL | Gnd | Ground pin for PLL section of IC. |
| 6 | 6 | $T_X$ PD | Output | Three state voltage output of the $T_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $T_X$ PLL loop filter. It is important to minimize the line length and capacitance on this pin. |
| 7 | 7 | E Cap | – | Expander rectifier filter capacitor pin. Connect capacitor to $V_{CC}$. |
| 8 | 8 | $T_X$ VCO | Input | Transmit divide counter input which is driven by an ac coupled external transmit loop VCO. The minimum signal level is 200 $mV_{pp}$ @ 80.0 MHz. This pin also functions as the test mode input for the counter tests. |
| 9<br>10<br>11 | 9<br>10<br>11 | Data<br>EN<br>Clk | Input | Microprocessor serial interface input pins for programming various counters and control functions. |
| 12 | 12 | Clk Out | Output | Microprocesor Clock Output which is derived from the 2nd LO crystal oscillator and a programmable divider. It can be used to drive a microprocessor and thereby reduce the number of crystals required in the system design. The driver has an internal resistor in series with the output whch can be combined with an external capacitor to form a low pass filter to reduce radiated noise on the PCB. This output also functions as the output for the counter test modes. |
| N/A | 14 | Status Out | Output | This pin indicates when the internal latches may have lost memory due to a power glitch. |
| 13 | 15 | CD Out/<br>Hardware<br>Interrupt | Output/<br>Input | Dual function pin; 1) Carrier detect output (open collector with external 100 kΩ pull–up resistor. 2) Hardware interrupt input which can be used to "wake–up" from Inactive Mode. |
| 14 | 16 | BD Out | Output | Low battery detect output (open collector with external pull–up resistor). |
| 15 | 17 | DA Out | Output | Data amplifier output (open collector with internal 100 kΩ pull–up resistor). |
| 16 | 18 | SA Out | Output | Speaker amplifier output. |
| 17 | 19 | SA In | Input | Speaker amplifier input (ac coupled). |
| 18 | 20 | E Out | Output | Expander output. |
| 19 | 21 | $V_{CC}$ Audio | Supply | $V_{CC}$ supply for audio section. |
| 20 | 22 | DA In | Input | Data amplifier input (ac coupled). |
| 21 | 23 | Pre–Amp Out | Output | Pre–amplifier output for connection of pre–amplifier feedback resistor. |
| 22 | 24 | $R_X$ Audio In | Input | $R_X$ audio input to pre–amplifier (ac coupled). |
| 23 | 25 | Det Out | Output | Audio output from FM detector. |
| 24 | 26 | RSSI | – | Receive signal strength indicator filter capacitor. |
| N/A | 27 | N/A | – | Note used. |
| 25 | 28 | Q Coil | – | A quad coil or ceramic discriminator are connected to this pin. |
| 26 | 29 | $V_{CC}$ RF | Supply | $V_{CC}$ supply for RF receiver section. |
| 27<br>28 | 30<br>31 | Lim C2<br>Lim C1 | – | IF amplifier/limiter capacitor pins. |

**PIN FUNCTION DESCRIPTION (continued)**

| 48–TQFP Pin | 52–QFP Pin | Symbol | Type | Description |
|---|---|---|---|---|
| 29 | 32 | Lim In | Input | Signal input for IF amplifier/limiter. |
| 30 | 33 | Gnd RF | Gnd | Ground pin for RF section of the IC. |
| 31 | 34 | $Mix_2$ Out | Output | Second mixer output. |
| 32 | 35 | $Mix_2$ In | Input | Second mixer input. |
| 33 | 36 | $V_B$ | – | Internal half supply analog ground reference. |
| 34 | 37 | $Mix_1$ Out | Output | First mixer output. |
| 35 | 38 | $Mix_1$ $In_2$ | Input | Negative polarity first mixer input. |
| 36 | 39 | $Mix_1$ $In_1$ | Input | Positive polarity first mixer input. |
| 37<br>38 | 40<br>41 | $LO_1$ In<br>$LO_1$ Out | – | Tank elements for 1st LO multivibrator oscillator are connected to these pins. |
| 39 | 42 | $V_{cap}$ Ctrl | – | 1st LO varactor control pin. |
| 40 | 43 | Gnd Audio | Gnd | Ground for audio section of the IC. |
| 41 | 44 | $T_X$ In | Input | $T_X$ path input to Microphone Amplifier (ac coupled). |
| 42 | 45 | Amp Out | Output | Microphone amplifier output. |
| 43 | 46 | C In | Input | Compressor input (ac coupled). |
| 44 | 47 | C Cap | – | Compressor rectifier filter capacitor pin. Connect capacitor to $V_{CC}$. |
| 45 | 48 | Lim Out | Output | $T_X$ path limiter output. |
| 46 | 49 | Spl Amp In | Input | Splatter amplifier input (ac coupled). |
| 47 | 50 | $T_X$ Out | Output | $T_X$ path audio output. |
| 48 | 51 | Ref | Input | Reference voltage input for low battery detect. |
| N/A | 52 | N/A | – | Not used. |

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### Power Supply Voltage

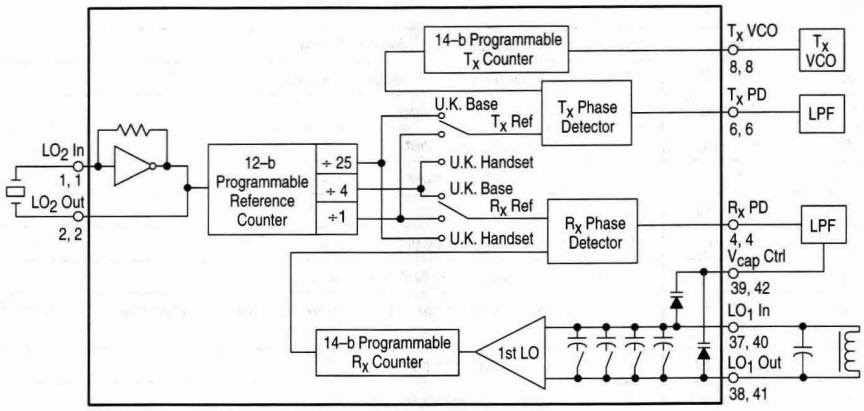
This circuit is used in a cordless telephone handset and base unit. The handset is battery powered and can operate on two ro three NiCad cells or on 5.0 V power.

### PLL Frequency Synthesizer General Description

Figure 8 shows a simplified block diagram of the programmable universal dual phase locked loop (PLL). This dual PLL is fully programmable thorugh the MCU serial interface and supports most country channel frequencies including USA (25 ch), France, Spain, Australia, Korea, New Zealand, U.K., Netherlands and China (see channel frequency tables in Appendix A).

The 2nd local oscillator and reference divider provide the reference frequency for the $R_X$ and $T_X$ PLL loops. The programmed divider value for the reference divider is selected based on the crystal frequency and the desired $R_X$ and $T_X$ reference frequency values. Additional divide by 25 and divide by 4 blocks are provided to allow for generation of the 1.0 kHz and 6.25 kHz reference frequencies required for the U.K. The 14–bit $T_X$ counter is programmed for the desired transmit channel frequency. The 14–bit $R_X$ counter is programmed for the desired first local oscillator frequency. All counters power up in the proper default state for USA channel #6 and for a 10.24 MHz reference frequency crystal. Internal fixed capacitors can be connected to the tank circuit of the 1st LO through microprocessor control to extend the sensitivity of the 1st LO for U.S. 25 channel operation.

**Figure 8. Dual PLL Simplified Block Diagram**




**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 2.6 V, $T_A$ = 25°C)

| Characteristic | Condition | Measure Pin | Symbol | Min | Max | Unit |
|---|---|---|---|---|---|---|
| **PLL PIN DC** | | | | | | |
| Input Voltage Low | – | Data<br>Clk<br>EN<br>Hardware Int. | $V_{IL}$ | – | 0.3 | V |
| Input Voltage High | – | Data<br>Clk<br>EN | $V_{IH}$ | "PLL $V_{ref}$" – 0.3 | "$V_{CC}$ Audio" | V |
| Input Current Low | $V_{in}$ = 0.3 V | Data<br>Clk<br>EN | $I_{IL}$ | –5.0 | – | µA |
| Input Current High | $V_{in}$ = ($V_{CC}$ Audio) – 0.3 | Data<br>Clk<br>EN | $I_{IH}$ | – | 5.0 | µA |
| Hysteresis Voltage | – | Data<br>Clk<br>EN | $V_{hys}$ | 1.0 | – | V |
| Output Current High | – | $R_X$ PD<br>$T_X$ PD | $I_{OH}$ | – | –0.7 | mA |
| Output Current Low | – | $R_X$ PD<br>$T_X$ PD | $I_{OL}$ | 0.7 | – | mA |
| Output Voltage Low | $I_{IL}$ = 0.7 mA | $R_X$ PD<br>$T_X$ PD | $V_{OL}$ | – | (PLL $V_{ref}$)* 0.2 | V |
| Output Voltage High | $I_{IH}$ = –0. 7mA | $R_X$ PD<br>$T_X$ PD | $V_{OH}$ | (PLL $V_{ref}$)* 0.8 | – | V |
| Tri–State Leakage Current | V = 1.2 V | $R_X$ PD<br>$T_X$ PD | $I_{OZ}$ | –50 | 50 | nA |
| Input Capacitance | – | Data<br>Clk<br>EN | $C_{in}$ | – | 8.0 | pF |
| Output Capacitance | – | $R_X$ PD<br>$T_X$ PD | $C_{out}$ | – | 8.0 | pF |

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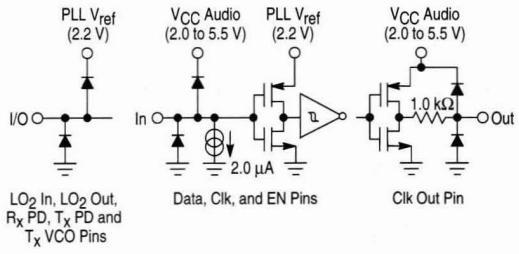
**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 2.6 V, $T_A$ = 25°C)

| Characteristic | Condition | Measure Pin | Symbol | Min | Max | Unit |
|---|---|---|---|---|---|---|
| **PLL PIN INTERFACE** | | | | | | |
| EN to Clk Setup Time | – | EN, Clk | $t_{suEC}$ | 200 | – | ns |
| Data to Clk Setup Time | – | Data, Clk | $t_{suDC}$ | 100 | – | ns |
| Hold Time | – | Data, Clk | $t_h$ | 90 | – | ns |
| Recovery Time | – | EN, Clk | $t_{rec}$ | 90 | – | ns |
| Input Pulse Width | – | EN, Clk | $t_w$ | 100 | – | ns |
| Input Rise and Fall Time | – | Data<br>Clk<br>EN | $t_r$, $t_f$ | –<br>–<br>– | 9.0<br>–<br>– | µs |
| MPU Interface Power–Up Delay | 90% of PLL $V_{ref}$ to Data, Clk, EN | – | $t_{puMPU}$ | – | 100 | µs |
| **PLL LOOP** | | | | | | |
| **Characteristic** | **Condition** | **Measure Pin** | **Symbol** | **Min** | **Max** | **Unit** |
| 2nd LO Frequency | – | $LO_2$ In<br>$LO_2$ Out | $f_{LO}$ | – | 12 | MHz |
| "$T_X$ VCO" Input Frequency | $V_{in}$ = 200 $mV_{pp}$ | $T_X$ VCO | $f_{txmax}$ | – | 80 | MHz |

### PLL I/O Pin Specifications

The 2nd LO, $R_X$ and $T_X$ PLL's and MPU serial interface are normally powered by the internal voltage regulator at the "PLL $V_{ref}$" pin. The "PLL $V_{ref}$" pin is the output of a voltage regulator which is powered from the "$V_{CC}$ Audio" power supply pin. Therefore, the maximum input and output levels for most PLL I/O pins ($LO_2$ In, $LO_2$ Out, $R_X$ PD, $T_X$ PD, $T_X$ VCO) is the regulated voltage at the "PLL $V_{ref}$" pin. The ESD protection diodes on these pins are also connected to "PLL $V_{ref}$". Internal level shift buffers are provided for the pins (Data, Clk, EN, Clk Out) which connect directly to the microprocessor. The maximum input and output levels for these pins is $V_{CC}$. Figure 9 shows a simplified schematic of the PLL I/O pins.

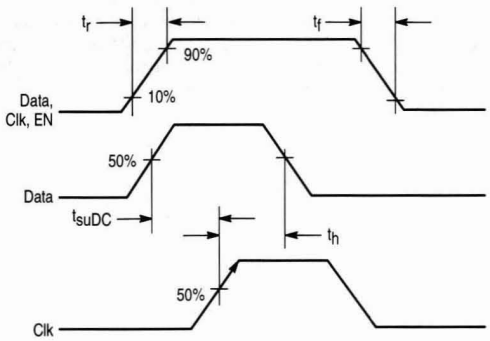
**Figure 9. PLL I/O Pin Simplified Schematics**




### Microprocessor Serial Interface

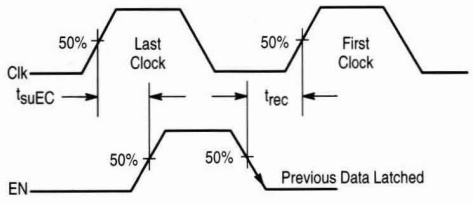
The "Data", "Clk", and "EN" pins provide an MPU serial interface for programming the reference counters, the transmit and receive channel divider counter and various control functions. The "Data" and "Clk" pins are used to load data into the shift register. Figure 10 shows "Data" and "Clk" pin timing. Data is clocked on positive clock transitions.

**Figure 10. Data and Clock Timing Requirement**



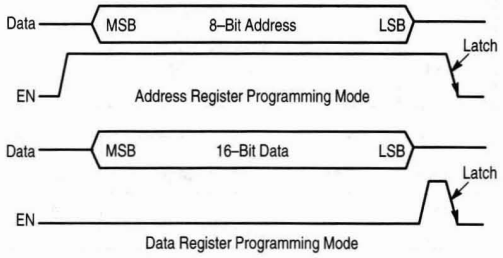

After data is loaded into the shift register, the data is latched into the appropriate latch register using the "EN" pin. This is done in two steps. First, an 8–bit address is loaded into the shift register and latched into the 8–bit address latch register. Then, up to 16–bits of data is loaded into the shift register and latched into the data latch register specified by the address that was previously loaded. Figure 11 shows the timing required on the EN pin. Latching occurs on the negative EN transition.

**Figure 11. Enable Timing Requirement**



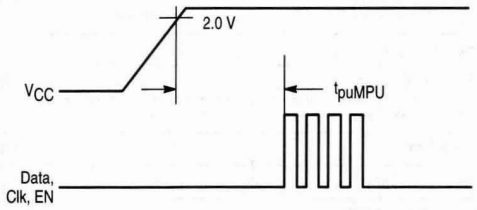
The state of the EN pin when clocking data into the shift register determines whether the data is latched into the address register or a data register. Figure 12 shows the address and data programming diagrams. In the data programming mode, there must not be any clock transitions when "EN" is high. The clock can be in a high state (default high) or a low state (default low) but must not have any transitions during the "EN" high state. The convention in these figures is that latch bits to the left are loaded into the shift register first.

**Figure 12. Microprocessor Interface Programming Mode Diagrams**




The MPU serial interface is fully operational within 100 μs after the power supply has reached its minimum level during power–up (See Figure 13). The MPU Interface shift registers and data latches are operational in all four power saving modes; Inactive, Standby, $R_X$, and Active Modes. Data can be loaded into the shift registers and latched into the latch registers in any of the operating modes.

**Figure 13. Microprocessor Serial Interface Power–Up Delay**




### Status Out

This is a digital output which indicates whether the latch registers have been reset to their power–up default values. Latch power–up default values are given in Figure 32. If there is a power glitch or ESD event which causes the latch registers to be reset to their default values, the "Status Out" pin will indicate this to the MPU so it can reload the correct information into the latch registers.

**Figure 14. Status Out Operation**

| Status Latch Register Bits | Status Out Logic Level |
|---|---|
| Latch bits not at power–up default value | 0 |
| Latch bits at power–up default value | 1 |

### Data Registers

Figure 15 shows the data latch registers and addresses which are used to select each of these registers. Latch bits to the left (MSB) are loaded into the shift register first. The LSB bit must always be the last bit loaded into the shift register. "Don't care" bits can be loaded into the shift register first if 8–bit bytes of data are loaded.

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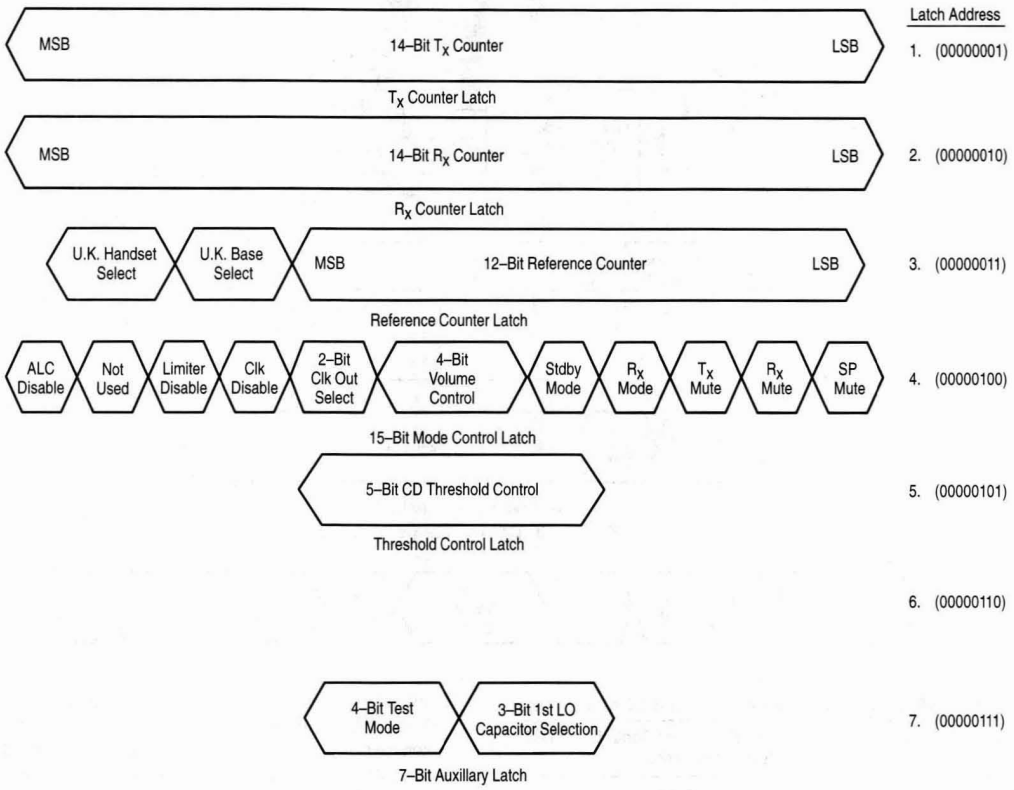
**Figure 15. Microprocessor Interface Data Latch Registers**

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### Reference Frequency Selection

The "$LO_2$ In" and "$LO_2$ Out" pins form a reference oscillator when connected to an external parallel–resonant crystal. The reference oscillator is also the second local oscillator for the RF Receiver. Figure 16 shows the relationship between different crystal frequencies and reference frequencies for cordless phone applications in various countries.

**Figure 16. Reference Frequency and Reference Divider Values**

| Crystal Frequency | Reference Divider Value | U.K. Base/ Handset Divider | Reference Frequency |
|---|---|---|---|
| 10.24 MHz | 2048 | 1 | 5.0 kHz |
| 10.24 MHz | 1024 | 4 | 2.5 kHz |
| 11.15 MHz | 2230 | 1 | 5.0 kHz |
| 12.00 MHz | 2400 | 1 | 5.0 kHz |
| 11.15 MHz | 1784 | 1 | 6.25 kHz |
| 11.15 MHz | 446 | 4 | 6.25 kHz |
| 11.15 MHz | 446 | 25 | 1.0 kHz |

### Reference Counter

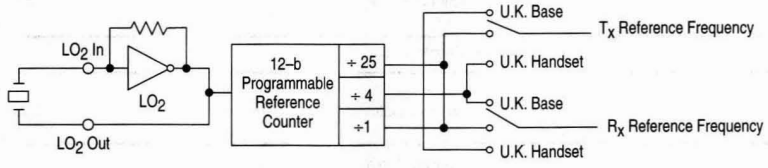
Figure 17 shows how the reference frequencies for the $R_X$ and $T_X$ loops are generated. All countries except U.K. require that the $T_X$ and $R_X$ reference frequencies be identical. In this case, set "U.K. Base Select" and "U.K. Handset Select" bits to "0". Then the fixed divider is set to "1" and the $T_X$ and $R_X$ reference frequencies will be equal to the crystal oscillator frequency divided by the programmable reference counter value. The U.K. is a special case which requires a different reference frequency value fo $T_X$ and $R_X$.

For U.K. base operation, set "U.K. Base Select" to "1". For U.K. handset operation, set "U.K. Handset Select" to "1". The Netherlands is also a special case since a 2.5 kHz reference frequency is used for both the $T_X$ and $R_X$ reference and the total divider value required is 4096 which is larger than the maximum divide value available from the 12–bit reference divider (4095). In this case, set "U.K. Base Select" to "1" and set "U.K. Handset Select" to "1". This will give a fixed divide by 4 for both the $T_X$ and $R_X$ reference. Then set the reference divider to 1024 to get a total divider of 4096.

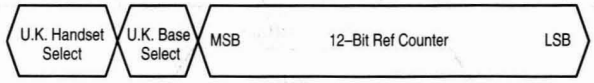
### Mode Control Register

Power saving modes, mutes, disables, volume control, and microprocessor clock output frequency are all set by the Control Register. Operation of the Control Register is explained in Figures 18 through 25.

**Figure 17. Reference Register Programming Mode**




| U.K. Handset Select | U.K. Base Select | $T_X$ Divider Value | $R_X$ Divider Value | Application |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | All but U.K. and Netherlands |
| 0 | 1 | 25 | 4 | U.K. Base Set |
| 1 | 0 | 4 | 25 | U.K. Hand Set |
| 1 | 1 | 4 | 4 | Netherlands Base and Hand Set |




14–Bit Reference Counter Latch

**Figure 18. Control Register Bits**

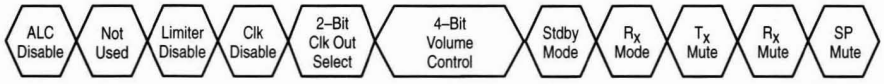



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**Figure 19. Mute and Disable Control Bit Descriptions**

| | | |
|---|---|---|
| ALC Disable | 1<br>0 | Automatic Level Control Disabled<br>Normal Operation |
| Limiter Disable | 1<br>0 | Limiter Disabled<br>Normal Operation |
| Clock Disable | 1<br>0 | MPU Clock Output Disabled<br>Normal Operation |
| $T_X$ Mute | 1<br>0 | Transmit Channel Muted<br>Normal Operation |
| $R_X$ Mute | 1<br>0 | Receive Channel Muted<br>Normal Operation |
| SP Mute | 1<br>0 | Speaker Amp Muted<br>Normal Operation |

**Power Saving Operating Modes**

When the MC13109 is used in a handset, it is important to conserve power in order to prolong battery life. There are five modes of operation; Active, $R_X$, Standby, Interrupt and Inactive. In Active Mode, all circuit blocks are powered. In $R_X$ mode, all circuitry is powered down exept for those circuit sections needed to receive a transmission from the base. In the Standby and Interrupt Modes, all circuitry is powered down except for the circuitry needed to provide the clock output for the microprocessor. In Inactive Mode, all circuitry is powered down except the MPU interface. Latch memory is maintained in all modes. Figure 20 shows the control register bit values for selection of each power saving mode and Figure 21 show the circuit blocks which are powered in each of these operating mode.

**Figure 20. Power Saving Mode Selection**

| Stdby Mode Bit | $R_X$ Mode Bit | "CD Out/Hardware Interrupt" Pin | Power Saving Mode |
|---|---|---|---|
| 0 | 0 | X | Active |
| 0 | 1 | X | $R_X$ |
| 1 | 0 | X | Standby |
| 1 | 1 | 1 or High Impedance | Inactive |
| 1 | 1 | 0 | Inactive |

**Figure 21. Circuit Blocks Powered During Power Saving Modes**

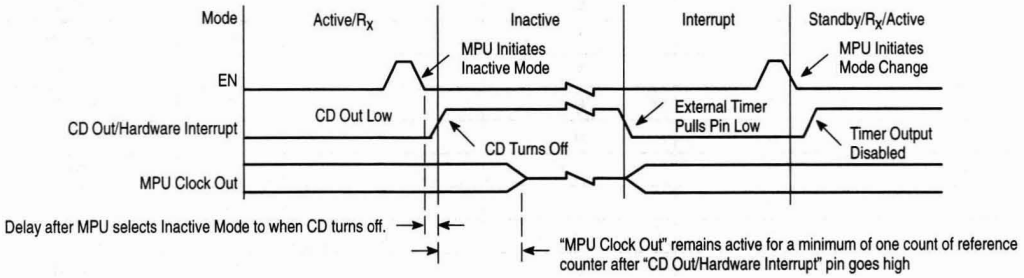
| Circuit Blocks | Active | $R_X$ | Standby | Inactive |
|---|---|---|---|---|
| "PLL $V_{ref}$" Regulated Voltage | X | X | X[1] | X[1] |
| MPU Interface | X | X | X | X |
| 2nd LO Oscillator | X | X | X | |
| MPU Clock Output | X | X | X | |
| RF Receiver | X | X | | |
| 1st LO VCO | X | X | | |
| $R_X$ PLL | X | X | | |
| Carrier Detect | X | X | | |
| Data Amp | X | X | | |
| Low Battery Detect | X | X | | |
| $T_X$ PLL | X | | | |
| $R_X$ Audio Path | X | | | |
| $T_X$ Audio Path | X | | | |

**NOTE:** 1. In Standby and Inactive Modes, "PLL $V_{ref}$" remains powered but is not regulated. It will fluctuate with $V_{CC}$.

### Inactive Mode Operation and Hardware Interrupt

In some handset applications it may be desirable to power down all circuitry including the microprocessor (MPU). First put the MC13109 into the Inactive mode, which turns off the MPU Clock Output (see Figure 22), and then disable the microprocessor. In order to give the MPU adequate time to power down, the MPU Clock output remains active for a minimum of one reference counter cycle (about 200 µs) after the command is given to switch into the "Inactive" mode. An external timing circuit should be used to initiate the turn–on sequence. The "CD Out" pin has a dual function. In the Active and $R_X$ modes it performs the carrier detect function. In the Standby and Inactive modes the carrier detect circuit is disabled and the "CD Out" pin is in a "High" state due to the external pull–up resistor. In the Inactive mode the "CD Out" pin is the input for the hardware interrupt function. When the "CD Out" pin is pulled "low" by the external timing circuit, the MC13109 swtiches from the Inactive to the Interrupt mode thereby turning on the MPU Clock Output. The MPU can then resume control of the combo IC. The "CD Out" pin must remain low until the MPU changes the operating mode from Interrupt to Standby, Active or $R_X$ modes.

**Figure 22. Hardware Interrupt Operation**


Mode
Active/RX
Inactive
Interrupt
Standby/RX/Active
MPU Initiates Inactive Mode
MPU Initiates Mode Change
EN
CD Out Low
External Timer Pulls Pin Low
CD Out/Hardware Interrupt
CD Turns Off
Timer Output Disabled
MPU Clock Out
Delay after MPU selects Inactive Mode to when CD turns off.
"MPU Clock Out" remains active for a minimum of one count of reference counter after "CD Out/Hardware Interrupt" pin goes high

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### "Clk Out" Divider Programming

The "Clk Out" pin is derived from the 2nd local oscillator and can be used to drive a microprocessor, thereby reducing the number of crystals required. Figure 23 shows the relationship between the crystal frequency and the clock output for different divider values. Figure 24 shows the "Clk Out" register bit values.

**Figure 23. Clock Output Values**

| Crystal Frequency | Clock Output Divider | | | |
|---|---|---|---|---|
| | 2 | 3 | 5 | 10 |
| 10.24 MHz | 5.120 MHz | 3.413 MHz | 2.560 MHz | 2.048 MHz |
| 11.15 MHz | 5.575 MHz | 3.717 MHz | 2.788 MHz | 2.230 MHz |
| 12.00 MHz | 6.000 MHz | 4.000 MHz | 3.000 MHz | 2.400 MHz |

**Figure 24. Clock Output Divider**

| Clk Out Bit #1 | Clk Out Bit #0 | Clk Out Divider Value |
|---|---|---|
| 0 | 0 | 2 |
| 0 | 1 | 3 |
| 1 | 0 | 5 |
| 1 | 1 | 10 |

### MPU "Clk Out" Power–Up Default Divider Value

The power–up default divider value is "divide by 10". This provides an MPU clock of about 1.0 MHz after initial power–up. The reason for choosing this relatively low clock frequency after intial power–up is that some microprocessors that operate down to a 2.0 V power supply have a maximum clock frequency fo 1.0 MHz. After initial power–up, the MPU can change the clock divider value to set the clock to the desired operating frequency. Special care has been taken in the design of the clock divider to ensure that the transition between one clock divider value and another is "smooth" (i.e., there will be no narrow clock pulses to disturb the MPU).

### MPU "Clk Out" Radiated Noise on Circuit Board

The clock line running between the MC13109 and the microprocessor has the potential to radiate noise which can cause problems in the system especially if the clock is a square wave digital signal with large high frequency harmonics. In order to minimize radiated noise, a 1.0 kΩ resistor is included on–chip in–series with the "Clk Out" output driver. A small capacitor can be connected to the "Clk Out" line on the PCB to form a single pole low pass filter. This filter will significantly reduce noise radiated from the "Clk Out" line.

### Volume Control

The volume control can be programmed in 2.0 dB gain steps from –14 dB to +16 dB. The power–up default value is 0 dB.

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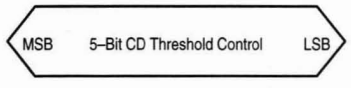
**Figure 25. Volume Control**

| Volume Control Bit #3 | Volume Control Bit #2 | Volume Control Bit #1 | Volume Control Bit #0 | Volume Control # | Gain/Attenuation Amount |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | –14 dB |
| 0 | 0 | 0 | 1 | 1 | –12 dB |
| 0 | 0 | 1 | 0 | 2 | –10 dB |
| 0 | 0 | 1 | 1 | 3 | –8.0 dB |
| 0 | 1 | 0 | 0 | 4 | –6.0 dB |
| 0 | 1 | 0 | 1 | 5 | –4.0 dB |
| 0 | 1 | 1 | 0 | 6 | –2.0 dB |
| 0 | 1 | 1 | 1 | 7 | 0 dB |
| 1 | 0 | 0 | 0 | 8 | 2.0 dB |
| 1 | 0 | 0 | 1 | 9 | 4.0 dB |
| 1 | 0 | 1 | 0 | 10 | 6.0 dB |
| 1 | 0 | 1 | 1 | 11 | 8.0 dB |
| 1 | 1 | 0 | 0 | 12 | 10 dB |
| 1 | 1 | 0 | 1 | 13 | 12 dB |
| 1 | 1 | 1 | 0 | 14 | 14 dB |
| 1 | 1 | 1 | 1 | 15 | 16 dB |

### Gain Control Register

The gain control register contains bits which control the Carrier Detect threshold. Operation of these latch bits are explained in Figures 26 and 27.

**Figure 26. Gain Control Latch Bits**



### Carrier Detect Threshold Programming

Th "CD Out" pin will give an indication to the microprocessor if a carier signal is present on the selected channel. The nominal value and tolerance of the carrier detect threshold is given in the carrier detect specification section of this document. If a different carrier detect threshold value is desired, it can be set through the MPU interface as shown in Figure 27 below.

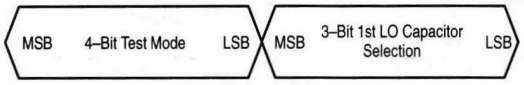
**Figure 27. Carrier Detect Threshold Control**

| CD Bit #4 | CD Bit #3 | CD Bit #2 | CD Bit #1 | CD Bit #0 | CD Control # | Carrier Detect Threshold |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | –20 dB |
| 0 | 0 | 0 | 0 | 1 | 1 | –19 dB |
| 0 | 0 | 0 | 1 | 0 | 2 | –18 dB |
| 0 | 0 | 0 | 1 | 1 | 3 | –17 dB |
| 0 | 0 | 1 | 0 | 0 | 4 | –16 dB |
| 0 | 0 | 1 | 0 | 1 | 5 | –15 dB |
| 0 | 0 | 1 | 1 | 0 | 6 | –14 dB |
| 0 | 0 | 1 | 1 | 1 | 7 | –13 dB |
| 0 | 1 | 0 | 0 | 0 | 8 | –12 dB |
| 0 | 1 | 0 | 0 | 1 | 9 | –11 dB |
| 0 | 1 | 0 | 1 | 0 | 10 | –10 dB |
| 0 | 1 | 0 | 1 | 1 | 11 | –9.0 dB |
| 0 | 1 | 1 | 0 | 0 | 12 | –8.0 dB |
| 0 | 1 | 1 | 0 | 1 | 13 | –7.0 dB |
| 0 | 1 | 1 | 1 | 0 | 14 | –6.0 dB |
| 0 | 1 | 1 | 1 | 1 | 15 | –5.0 dB |
| 1 | 0 | 0 | 0 | 0 | 16 | –4.0 dB |
| 1 | 0 | 0 | 0 | 1 | 17 | –3.0 dB |
| 1 | 0 | 0 | 1 | 0 | 18 | –2.0 dB |
| 1 | 0 | 0 | 1 | 1 | 19 | –1.0 dB |
| 1 | 0 | 1 | 0 | 0 | 20 | 0 dB |
| 1 | 0 | 1 | 0 | 1 | 21 | 1.0 dB |
| 1 | 0 | 1 | 1 | 0 | 22 | 2.0 dB |
| 1 | 0 | 1 | 1 | 1 | 23 | 3.0 dB |
| 1 | 1 | 0 | 0 | 0 | 24 | 4.0 dB |
| 1 | 1 | 0 | 0 | 1 | 25 | 5.0 dB |
| 1 | 1 | 0 | 1 | 0 | 26 | 6.0 dB |
| 1 | 1 | 0 | 1 | 1 | 27 | 7.0 dB |
| 1 | 1 | 1 | 0 | 0 | 28 | 8.0 dB |
| 1 | 1 | 1 | 0 | 1 | 29 | 9.0 dB |
| 1 | 1 | 1 | 1 | 0 | 30 | 10 dB |
| 1 | 1 | 1 | 1 | 1 | 31 | 11 dB |

### Auxiliary Register

The auxiliary register contains a 3–bit 1st LO Capacitor Selection latch and a 4–bit Test Mode latch. Operation of these latch bits are explained in Figures 28, 29 and 30.

**Figure 28. Auxiliary Register Latch Bits**




### First Local Oscillator Capacitor Selection for 25 Channel U.S. Operation

There is a very large frequency difference between the minimum and maximum channel frequencies in the proposed 25 Channel U.S. standard. The sensitivity of the 1st LO is not large enough to accommodate this large frequency variation. Fixed capacitors can be connected across the 1st LO tank circuit to change the 1st LO sensitivity. Internal switches and capacitors are provided to enable microprocessor control over internal fixed capacitor values. Figure 29 shows the schematic of the 1st LO tank circuit. Figure 30 shows the latch control bit values.

The internal varactor temperature coefficient is 1800 ppm/°C ($C_O$ = 8.9 pF at 25°C, $V_{cap}$ control voltage = 1.2 V, $F_{req}$ = 36 MHz). Customer is suggested to use a negative temperature coefficient capacitor in 1st LO tank circuit when the whole operating temperature range of –40 to +85°C is considered.

**Figure 29. 1st LO Schematic**

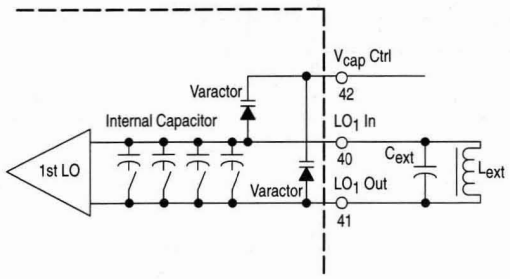



**Figure 30. 1st LO Capacitor Select for U.S. 25 Channels**

| 1st LO Cap. Bit 2 | 1st LO Cap. Bit 1 | 1st LO Cap Bit 0 | 1st LO Cap. Select | U.S. Base Channels | U.S. Handset Channels | Internal Cap. Value (Excluding Varactor) | Varactor Value over 0.5 to 2.2 V Range | External Capacitor Value | External Inductor Value |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 16 – 25 | – | 0.92 pF | 10 – 6.4 pF | 27 pF | 0.47 µH |
| 0 | 0 | 0 | 0 | – | 16 – 25 | 0.92 pF | 10 – 6.4 pF | 33 pF | 0.47 µH |
| 0 | 0 | 1 | 1 | 1 – 6 | – | 2.61 pF | 10 – 6.4 pF | 27 pF | 0.47 µH |
| 0 | 1 | 0 | 2 | 7 – 15 | – | 1.82 pF | 10 – 6.4 pF | 27 pF | 0.47 µH |
| 0 | 1 | 1 | 3 | – | 1 – 6 | 8.69 pF | 10 – 6.4 pF | 33 pF | 0.47 µH |
| 1 | 0 | 0 | 4 | – | 7 – 15 | 7.19 pF | 10 – 6.4 pF | 33 pF | 0.47 µH |

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**Figure 31. Test Mode Description**

| TM # | TM 3 | TM 2 | TM 1 | TM 0 | Counter Under Test or Test Mode Option | "$T_X$ $V_{CO}$" Input Signal | "Clk Out" Output Expected |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | Normal Operation | >200 $mV_{pp}$ | – |
| 1 | 0 | 0 | 0 | 1 | $R_X$ Counter, upper 6 | 0 to 2.2 V | Input Frequency/64 |
| 2 | 0 | 0 | 1 | 0 | $R_X$ Counter, lower 8 | 0 to 2.2 V | See Note Below |
| 3 | 0 | 0 | 1 | 1 | $R_X$ Prescaler | 0 to 2.2 V | Input Frequency/4 |
| 4 | 0 | 1 | 0 | 0 | $T_X$ Counter, upper 6 | 0 to 2.2 V | Input Frequency/64 |
| 5 | 0 | 1 | 0 | 1 | $T_X$ Counter, lower 8 | 0 to 2.2 V | See Note Below |
| 6 | 0 | 1 | 1 | 0 | $T_X$ Prescaler | >200 $mV_{pp}$ | Input Frequency/4 |
| 7 | 0 | 1 | 1 | 1 | Reference Counter | 0 to 2.2 V | Input Frequency/Reference Counter Value |
| 8 | 1 | 0 | 0 | 0 | Divide by 4, 25 | 0 to 2.2 V | Input Frequency/100 |
| 9 | 1 | 0 | 0 | 1 | AGC Gain = 10 Option | N/A | – |
| 10 | 1 | 0 | 1 | 0 | AGC Gain = 25 Option | N/A | – |

**NOTE:** To determine the correct output, look at the lower 8 bits in the $R_X$ or $T_X$ register (Divisor (7;0). If the value of the divisor is > 16, then the output divisor value is Divisor (7;2) (the upper 6 bits of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) > = 2, then output divisor value is Divisor (3;2) (bits 2 and 3 of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) < 2, then output divisor value is (Divisor (3;2) + 60).

### Test Modes

Test Mode Control latch bits enable independent testing of internal counters and set AGC Gain Options. In test mode, the "$T_X$ VCO" input pin is multiplexed to the input of the counter under test and the output of the counter under test is multiplexed to the "Clk Out" output pin so that each counter can be individually tested. Make sure test mode bits are set to "0" for normal operation. Test mode operation is described in Figure 31. During normal operation and when testing the $T_X$ Prescaler, the "$T_X$ VCO" input can be a minimum of 200 $mV_{pp}$ at 80 MHz and should be ac coupled. For other test modes, input signals should be standard logic levels of 0 to 2.2 V and a maximum frequency of 16 MHz.

### Power–Up Defaults for Control and Counter Registers

When the IC is first powered up, all latch registers are initialized to a defined state. The MC13109 is initially placed in the Rx mode with all mutes active and nothing disabled. The reference counter is set to generate a 5.0 kHz reference frequency from a 10.24 MHz crystal. The MPU clock output divider is set to 10 to give the minimum clock output frequency. The $T_X$ and $R_X$ latch registers are set for USA Channel Frequency #21. Figure 32 shows the initial power–up states for all latch registers.

**Figure 32. Latch Register Power–Up Defaults**

| | | MSB | | | | | | | | LSB | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Register | Count | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| $T_X$ | 9966 | – | – | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| $R_X$ | 7215 | – | – | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| Ref | 2048 | – | – | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mode | N/A | – | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Gain | N/A | – | – | – | – | – | – | – | – | – | – | – | 1 | 0 | 1 | 0 | 0 |
| TM | N/A | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Figure 33. $I_{CC}$ versus $V_{CC}$ at Active Mode**

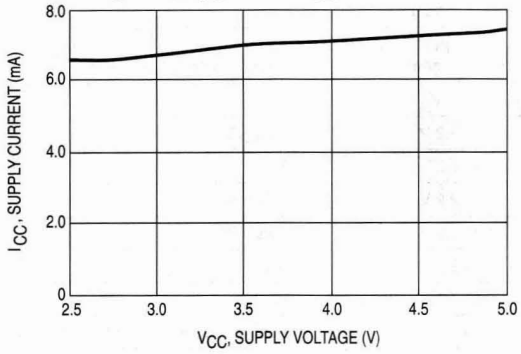


**Figure 34. $I_{CC}$ versus $V_{CC}$ at Receive Mode**

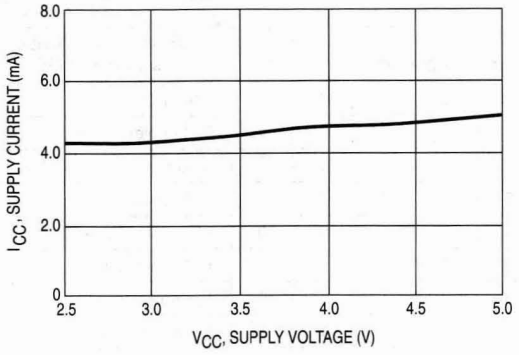


**Figure 35. $I_{CC}$ versus $V_{CC}$ at Standby Mode**

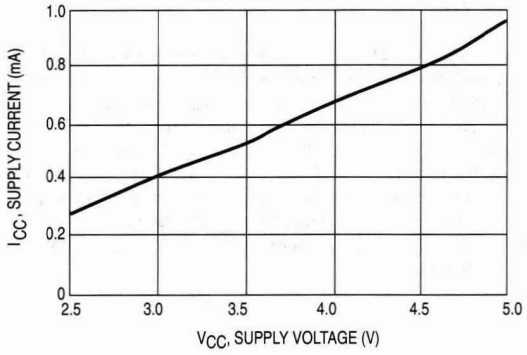


**Figure 36. $I_{CC}$ versus $V_{CC}$ at Inactive Mode**

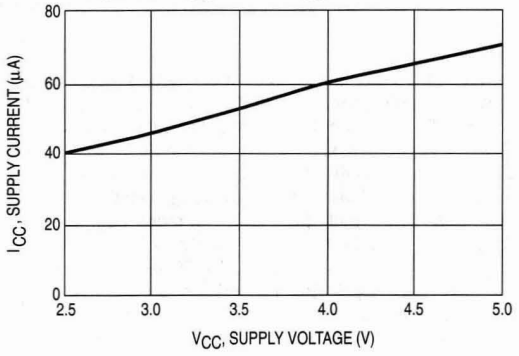


**Figure 37. $RF_{in}$ versus $AF_{out}$, N+D, N, AMR**

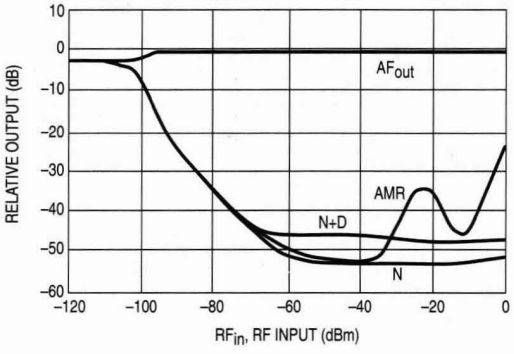


**Figure 38. Recovered Audio/THD versus $f_{DEV}$**

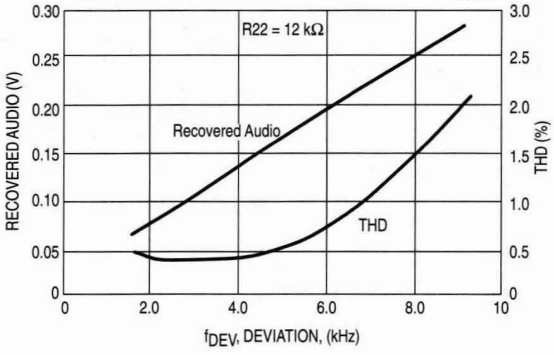


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**Figure 39. RSSI Output versus $RF_{in}$**

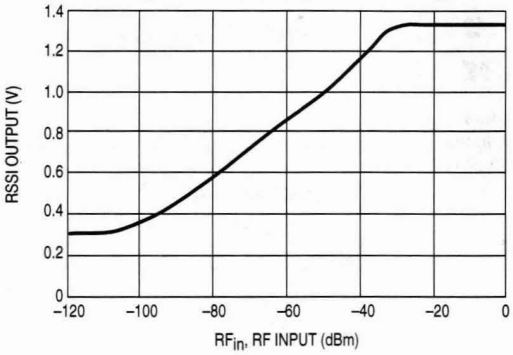
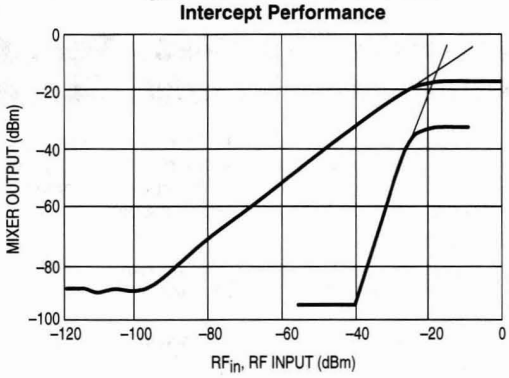



**Figure 40. First Mixer Third Order Intercept Performance**




## APPENDIX A – MEASUREMENT OF COMPANDOR ATTACK/DECAY TIME

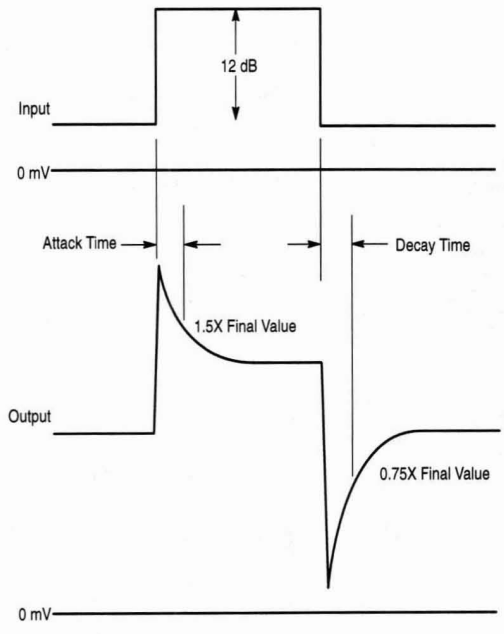
This measurement definition is based on EIA/CCITT recommendations.

**Compressor Attack Time**

For a 12 dB step up at the input, attack time is defined as the time for the output to settle to 1.5X of the final steady state value.

**Compressor Decay Time**

For a 12 dB step down at the input, decay time is defined as the time for the input to settle to 0.75X of the final steady state value.

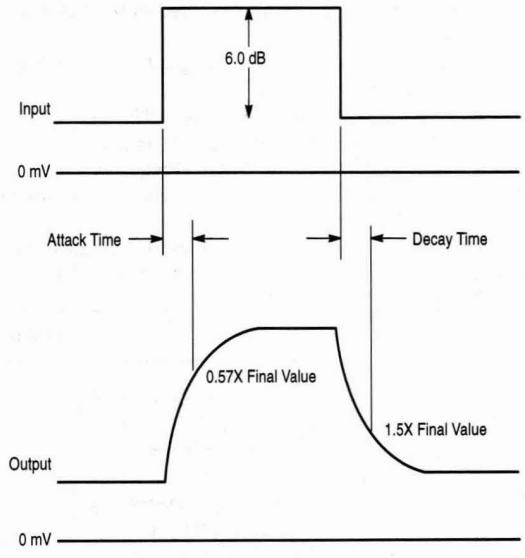



**Expander Attack**

For a 6.0 dB step up at the input, attack time is defined as the time for the output to settle to 0.57X of the final steady state value.

**Expander Decay**

For a 6.0 dB step down at the input, decay time is defined as the time for the output to settle to 1.5X of the final steady state value.




8

MOTOROLA

# Universal Cordless Telephone Subsystem IC with Scrambler

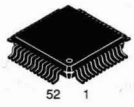
**MC13110**

**UNIVERSAL CT–1 SUBSYSTEM INTEGRATED CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13110 integrates several of the functions required for a cordless telephone into a single integrated circuit. This significantly reduces component count, board space requirements, and external adjustments. It is designed for use in both the handset and the base.

- Dual Conversion FM Receiver
  - Complete Dual Conversion Receiver – Antenna In to Audio Out 80 MHz Maximum Carrier Frequency
  - RSSI Output
  - Carrier Detect Output with Programmable Threshold
  - Comparator for Data Recovery
  - Operates with Either a Quad Coil or Ceramic Discriminator
- Compander
  - Expandor Includes Mute, Digital Volume Control, Speaker Driver, 3.5 kHz Low Pass Filter, and Programmable Gain Block
  - Compressor Includes Mute, 3.5 kHz Low Pass Filter, Limiter, and Programmable Gain Block
- Dual Universal Programmable PLL
  - Supports New 25 Channel U.S. Standard with New External Switches
  - Universal Design for Domestic and Foreign CT–1 Standards
  - Digitally Controlled Via a Serial Interface Port
  - Receive Side Includes 1st LO VCO, Phase Detector, and 14–Bit Programmable Counter and 2nd LO with 12–Bit Counter
  - Transmit Section Contains Phase Detector and 14–Bit Counter
  - MPU Clock Outputs Eliminates Need for MPU Crystal
- Supply Voltage Monitor
  - Provides Two Levels of Monitoring with Separate Outputs
  - Separate, Adjustable Trip Points
- Frequency Inversion Scrambler/Descrambler
  - Can Be Enabled/Disabled Via MPU Interface
  - Programmable Carrier Modulation Frequency
- 2.7 to 5.5 V Operation with One–Third the Power Consumption of Competing Devices
- AN1575: Refer to this Application Note for a List of the "Worldwide Cordless Telephone Frequencies" (List can also be found in Chapter 8 Addendum of DL128 Data Book)

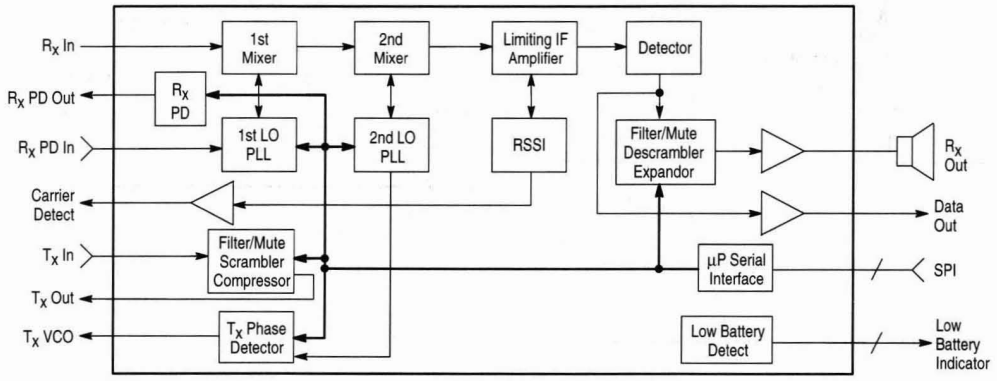



**FB SUFFIX**
PLASTIC QFP PACKAGE
CASE 848B

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC13110FB | $T_A$ = – 40° to +85°C | QFP–52 |

**Simplified Application**




This device contains 8,262 active transistors.

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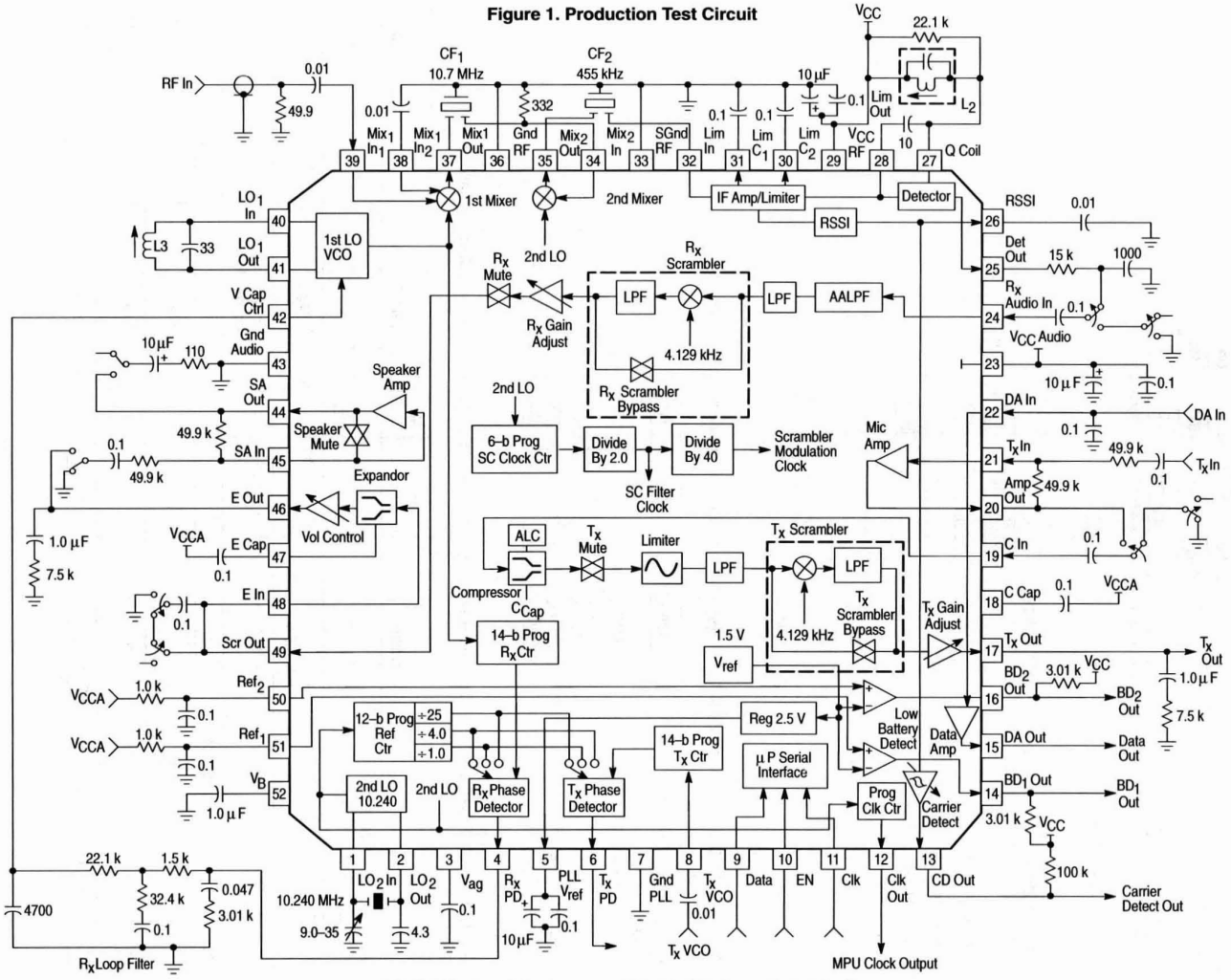
**Figure 1. Production Test Circuit**




**NOTE:** This schematic is only a representation of the actual production test circuit.

## MAXIMUM RATINGS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | −0.5 to +5.5 | Vdc |
| Junction Temperature | $T_J$ | −65 to +150 | °C |

**NOTES:** 1. Devices should not be operated at these limits. The "Recommended Operating Conditions" provide for actual device operation.

2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 2.7 | 3.6 | 5.0 | Vdc |
| Operating Ambient Temperature | $T_A$ | –40 | – | 85 | °C |
| Input Voltage Low (Data, Clk, EN) | $V_{IL}$ | – | – | 0.3 | V |
| Input Voltage High (Data, Clk, EN) | $V_{IH}$ | 2.5 | – | – | V |
| Output Current ($R_X$ PD, $T_X$ PD)<br>High<br>Low | <br>$I_{OH}$<br>$I_{OL}$ | <br>–<br>0.7 | <br>–<br>– | <br>–0.7<br>– | mA |

**NOTE:** All limits are not necessarily functional concurrently.

## DC ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 3.6 V, $T_A$ = 25°C, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Static Current | | | | | |
| Active Mode (2.7 V) | ACT $I_{CC}$ | – | 8.1 | – | mA |
| Active Mode | ACT $I_{CC}$ | – | 8.6 | 12 | mA |
| Receive Mode | $R_X$ $I_{CC}$ | – | 4.3 | 5.3 | mA |
| Standby Mode | STD $I_{CC}$ | – | 270 | 500 | µA |
| Inactive Mode | INACT $I_{CC}$ | – | 35 | 80 | µA |

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## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **PLL VOLTAGE REGULATOR** | | | | | | | | |
| Regulated Output Level | $I_L$ = 0 mA | – | PLL $V_{ref}$ | $V_O$ | 2.4 | 2.5 | 2.6 | V |
| Line Regulation | $I_L$ = 0 mA, $V_{CC}$ = 3.6 to 5.5 V | $V_{CC}$ Audio | PLL $V_{ref}$ | $V_{Reg}$ Line | – | –0.6 | 20 | mV |
| Load Regulation | $V_{CC}$ = 3.6 V, $I_L$ = 1.0 mA | $V_{CC}$ Audio | PLL $V_{ref}$ | $V_{Reg}$ Load | – | –1.1 | 20 | mV |
| **PLL LOOP CHARACTERISTICS** | | | | | | | | |
| 2nd LO Frequency (No Crystal) | – | $LO_2$ In | – | $f_{2ext}$ | – | 12 | – | MHz |
| 2nd LO Frequency (With Crystal) | – | – | $LO_2$ In $LO_2$ Out | $f_{2ext}$ | – | 12 | – | MHz |
| $T_X$ VCO (Input Frequency) | $V_{in}$ = 200 mVpp | – | $T_X$ VCO | $f_{txmax}$ | – | 80 | – | MHz |

**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_x$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **PLL PHASE DETECTOR** | | | | | | | | |
| Output Voltage Low | $I_{IL}$ = 0.7 mA | – | $R_x$ PD<br>$T_x$ PD | $V_{OL}$ | – | – | (PLL $V_{ref}$) *.2 | V |
| Output Voltage High | $I_{IH}$ = –0.7 mA | – | $R_x$ PD<br>$T_x$ PD | $V_{OL}$ | (PLL $V_{ref}$) *.8 | – | – | V |
| 3–State Leakage Current | V = 1.2 V | – | $R_x$ PD<br>$T_x$ PD | $I_{OZ}$ | –50 | – | 50 | nA |
| Output Capacitance | – | – | $R_x$ PD<br>$T_x$ PD | $C_{out}$ | – | 8.0 | – | pF |
| Output Rise and Fall Time | $C_{Load}$ = 50 pF | – | $R_x$ PD<br>$T_x$ PD<br>Clk Out | $t_r$, $t_f$ | – | 250 | – | ns |
| **MICROPROCESSOR SERIAL INTERFACE** | | | | | | | | |
| Input Current Low | $V_{in}$ = 0.3 V<br>Standby Mode | – | Data,<br>Clk, EN | $I_{IL}$ | –5.0 | 0.3 | – | µA |
| Input Current High | $V_{in}$ = 3.3 V<br>Standby Mode | – | Data,<br>Clk, EN | $I_{IH}$ | – | 1.5 | 5.0 | µA |
| Hysteresis Voltage | – | – | Data,<br>Clk, EN | $V_{hys}$ | – | 1.0 | – | V |
| Maximum Clock Frequency | – | Data,<br>EN, Clk | – | – | – | 2.0 | – | MHz |
| Input Capacitance | – | Data,<br>Clk, EN | – | $C_{in}$ | – | 8.0 | – | pF |
| EN to Clk Setup Time | – | – | EN, Clk | $t_{suEC}$ | – | 200 | – | ns |
| Data to Clk Setup Time | – | – | Data, Clk | $t_{suDC}$ | – | 100 | – | ns |
| Hold Time | – | – | Data, Clk | $t_h$ | – | 90 | – | ns |
| Recovery Time | – | – | EN, Clk | $t_{rec}$ | – | 90 | – | ns |
| Input Pulse Width | – | – | EN, Clk | $t_w$ | – | 100 | – | ns |
| Input Rise and Fall Time | – | – | Data,<br>Clk, EN | $t_r$, $t_f$ | – | 9.0 | – | µs |
| MPU Interface Power–Up Delay | 90% of PLL $V_{ref}$ to Data, Clk, EN | – | – | $t_{puMPU}$ | – | 100 | – | µs |
| **FM RECEIVER** ($f_{RF}$ = 46.77 MHz [USA Ch 21], $f_{dev}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz) | | | | | | | | |
| Sensitivity (Input for 12 dB SINAD) | 50 Ω Termination | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | 2.8<br>–98 | –<br>– | µVrms<br>dBm |
| | Single–Ended, Matched Input | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | 1.0<br>–107 | –<br>– | µVrms<br>dBm |
| | Differential, Matched Input | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | .56<br>–112 | –<br>– | µVrms<br>dBm |
| 1st Mixer Voltage Conversion Gain | $V_{in}$ = 1.0 mVrms, with $CF_1$ Filter as Load | $Mix_1$ $In_{1/2}$ | $Mix_1$ Out | $MX_{gain1}$ | – | 12 | – | dB |
| 2nd Mixer Voltage Conversion Gain | $V_{in}$ = 3.0 mVrms, with $CF_2$ Filter as Load | $Mix_2$ In | $Mix_2$ Out | $MX_{gain2}$ | – | 20 | – | dB |
| 1st and 2nd Mixer Voltage Gain Total | $V_{in}$ = 1.0 mVrms, with $CF_1$ and $CF_2$ Load | $Mix_1$ $In_{1/2}$ | $Mix_2$ Out | $MX_{gainT}$ | 24 | 28 | – | dB |
| 1st Mixer Input Impedance | Single–Ended Input | – | $Mix_1$ $In_{1/2}$ | $R_{P1}$<br>$C_{P1}$ | –<br>– | 875<br>2.7 | –<br>– | Ω<br>pF |
| 2nd Mixer Input Impedance | $f_{in}$ = 10.7 MHz | – | $Mix_2$ In | $Z_{in2}$ | – | 3.0 | – | kΩ |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_x$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **FM RECEIVER** ($f_{RF}$ = 46.77 MHz [USA Ch 21], $f_{dev}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz) | | | | | | | | |
| 1st Mixer Output Impedancet | – | – | $Mix_1$ Out | $Z_{out1}$ | – | 330 | – | Ω |
| 2nd Mixer Output Impedance | – | – | $Mix_2$ Out | $Z_{out2}$ | – | 1.5 | – | kΩ |
| IF –3.0 dB Limiting Sensitivity | $f_{in}$ = 455 kHz | Lim In | Det Out | IF Sens | – | 71 | 100 | μVrms |
| Total Harmonic Distortion | With $R_C$ = 15 k/1.0 nF Filter at Det Out | $Mix_1$ $In_1$ | Det Out | THD | – | 1.3 | 2.0 | % |
| Recovered Audio | $V_{in}$ = 3.16 mVrms with $R_C$ = 15 k/1000 pF Filter at Det Out | $Mix_1$ $In_1$ | Det Out | AFO | 80 | 105 | 150 | mVrms |
| Demodulator Bandwidth | – | Lim In | Det Out | BW | – | 20 | – | kHz |
| Signal to Noise Ratio | $V_{in}$ = 3.16 mVrms, $R_C$ = 15 k/1000 pF | $Mix_1$ $In_1$ | Det Out | SN | – | 49 | – | dB |
| AM Rejection Ratio | $V_{in}$ = 3.16 mVrms, 30% AM, @ 1.0 kHz, $R_C$ = 15 k/1000 pF | $Mix_1$ $In_1$ | Det Out | AMR | 30 | 47 | – | dB |
| 1st Mixer, 1.0 dB Voltage Compression (Input Pin Referred) | – | $Mix_1$ $In_{1/2}$ | $Mix_1$ Out | $V_O$ 1.0 dB $Mix_1$ | – | 15 | – | mVrms |
| 2nd Mixer, 1.0 dB Voltage Compression (Input Pin Referred) | 50 Ω Input | $Mix_2$ In | $Mix_2$ Out | $V_O$ 1.0 dB $Mix_2$ | – | 14 | – | mVrms |
| 1st Mixer 3rd Order Intercept (Input Pin Referred) | $V_{in}$ = 3.98 mVrms | $Mix_1$ $In_1$ | $Mix_1$ Out | $TOI_{mix1}$ | – | 56 | – | mVrms |
| 2nd Mixer 3rd Order Intercept (Input Pin Referred) | $V_{in}$ = 3.98 mVrms, 50 Ω Input | $Mix_2$ In | $Mix_2$ Out | $TOI_{mix2}$ | – | 53 | – | mVrms |
| Detector Output Impedance | – | – | Det Out | $Z_O$ | – | 870 | – | Ω |
| **RSSI/CARRIER DETECT** ($R_L$ = 100 kΩ) | | | | | | | | |
| RSSI Output Current Dynamic Range | – | $Mix_1$ In | RSSI | RSSI | – | 80 | – | dB |
| Carrier Sense Threshold | CD Threshold Adjust = (10100) | $Mix_1$ In | CD Out | $V_T$ | – | 33 | – | μVrms |
| Hysteresis | – | Mix1 In | CD Out | Hys | – | 3.6 | 7.0 | dB |
| Output High Voltage | $V_{in}$ = 0 Vrms, CD = (10100) | $Mix_1$ In | CD Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in}$ = –80 dBV, CD = (10100) | $Mix_1$ In | CD Out | $V_{OL}$ | – | 0.02 | 0.4 | V |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **RSSI/CARRIER DETECT** ($R_L$ = 100 kΩ) | | | | | | | | |
| Carrier Sense Threshold Adjustment Range | Programmable through MPU Interface | – | – | $V_{T\ low\ range}$ | –20 | – | – | dB |
| | | – | – | $V_{T\ hi\ range}$ | – | – | 11 | |
| Carrier Sense Threshold – Number of Steps | Programmable through MPU Interface | – | – | $V_{Tn}$ | – | 32 | – | – |
| **DATA AMP COMPARATOR** | | | | | | | | |
| Hysteresis | – | DA In | DA Out | Hys | 30 | 40 | 50 | mV |
| Threshold Voltage | – | DA In | DA Out | $V_T$ | 2.7 | $V_{CC}$ – 0.7 | – | V |
| Input Impedance | – | – | DA In | $Z_I$ | – | 11 | – | kΩ |
| Output Impedance | – | – | DA Out | $Z_O$ | – | 100 | – | kΩ |
| Output High Voltage | $V_{in} = V_{CC} – 1.0$ V, $I_{OH}$ = 0 mA | DA In | DA Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in} = V_{CC} – 0.4$ V, $I_{OL}$ = 0 mA | DA In | DA Out | $V_{OL}$ | – | 0.04 | 0.4 | V |
| **EXPANDOR/$R_X$ MUTE** ($f_{in}$ = 1.0 kHz) | | | | | | | | |
| Absolute Gain | $V_{in}$ = –20 dBV | E In | E Out | G | –3.0 | 0 | 3.0 | dB |
| Gain Tracking | $V_{in}$ = –30 dBV<br>$V_{in}$ = –40 dBV | E In | E Out | $G_t$ | –21<br>–42 | –20<br>–40 | –19<br>–38 | dB |
| Total Harmonic Distortion | $V_{in}$ = –20 dBV | E In | E Out | THD | – | 0.5 | 1.0 | % |
| Maximum Input Voltage | – | $R_X$ Audio In | – | – | – | –11.5 | – | dBV |
| Maximum Output Voltage | Increase input voltage until output voltage THD = 5.0%, then measure output voltage. $R_L$ = 7.5 k/1.0 µF | E In | E Out | $V_{Omax}$ | – | 0 | – | dBV |
| Input Impedance | – | $R_X$ Audio In<br>E In | – | $Z_{in}$ | –<br>– | 600<br>7.5 | –<br>– | kΩ |
| Attack Time | $E_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | E In | E Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $E_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | E In | E Out | $t_r$ | – | 13.5 | – | ms |
| Compressor to Expandor Crosstalk | $V_{in}$ = –10 dBV, $V_{(E\ In)}$ = AC Gnd | C In | E Out | $C_T$ | – | –90 | –70 | dB |
| $R_X$ Data Muting (Δ Gain) | $V_{in}$ = –20 dBV, $R_X$ Gain Adj = (01111) | $R_X$ Audio In | E Out | $M_e$ | – | –83 | –60 | dB |
| **SPEAKER AMP/SP MUTE** | | | | | | | | |
| Maximum Output Swing | $V_{in}$ = 0 dBV, $R_L$ = 130 Ω | SA In | SA Out | $V_{Omax}$ | 0.8 | 0.9 | – | Vpp |
| Speaker Amp Muting | $V_{in}$ = –20 dBV | SA In | SA Out | $M_{sp}$ | – | –90 | –60 | dB |
| **COMPRESSOR/$T_X$ MUTE** ($f_{in}$ = 1.0 kHz, Scrambler Bypass Mode, $T_X$ Gain Adj = (01111), $f_{in}$ = 1.0 kHz) | | | | | | | | |
| Absolute Gain | $V_{in}$ = –10 dBV | $T_X$ In | $T_X$ Out | G | –4.0 | 0 | 4.0 | dB |
| Gain Tracking | $V_{in}$ = –30 dBV<br>$V_{in}$ = –40 dBV | $T_X$ In | $T_X$ Out | $G_t$ | –11<br>–17 | –10<br>–20 | –9.0<br>–13 | dB |
| Total Harmonic Distortion | $V_{in}$ = –10 dBV | $T_X$ In | $T_X$ Out | THD | – | 0.6 | 1.1 | % |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **COMPRESSOR/$T_X$ MUTE** ($f_{in}$ = 1.0 kHz, Scrambler Bypass Mode, $T_X$ Gain Adj = (01111), $f_{in}$ = 1.0 kHz) | | | | | | | | |
| Maximum Output Voltage | Increase input voltage until output voltage THD = 5.0%, then measure output voltage. $R_L$ = 7.5 k/1.0 µF | C In | $T_X$ Out | $V_{Omax}$ | – | –5.0 | – | dBV |
| Input Impedance | – | C In | $T_X$ Out | $Z_{in}$ | – | 10 | – | kΩ |
| Attack Time | $C_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | C In | $T_X$ Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $C_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | C In | $T_X$ Out | $t_r$ | – | 13.5 | – | ms |
| Expandor to Compressor Crosstalk | $V_{in}$ = –20 dBV, Speaker Amp No Load, $V_{(C\ In)}$ = AC Gnd | E In | $T_X$ Out | $C_T$ | – | –60 | –40 | dB |
| $T_X$ Muting | $V_{in}$ – 10 dBV | $T_X$ In | $T_X$ Out | $M_C$ | – | –90 | –60 | dB |
| ALC Output Level | $V_{in}$ = –10 dBV<br>$V_{in}$ = –2.5 dBV<br>Limiter and Mutes disabled | $T_X$ In | $T_X$ Out | $ALC_{out}$ | –15<br>–13 | –11<br>–10 | –8.0<br>–6.0 | dBV |
| Limiter Output Level | $V_{in}$ = –2.5 dBV, ALC disabled | $T_X$ In | $T_X$ Out | $V_{lim}$ | –10 | –7.0 | – | dBV |
| **$R_X$ AND $T_X$ SCRAMBLER** (2nd LO = 10.24 MHz, $T_X$ Gain Adj = (01111), $R_X$ Gain Adj = (01111), Volume Control = (0 dB Default Levels), SCF Clock Divider = 31. Total is divide by 62 for SCF clock frequency of 165.16 kHz) | | | | | | | | |
| $R_X$ High Frequency Corner (Note 1) | $R_X$ Path, f = 479 Hz, V $R_X$ Audio In = –20 dBV | $R_X$ Audio In | Scr Out | $R_X$ $f_{ch}$ | – | 3.65 | – | kHz |
| $T_X$ High Frequency Corner (Note 1) | $T_X$ Path, f = 250 Hz, V $T_X$ In = –10 dBV, Mic Amp = Unity Gain | $T_X$ In | $T_X$ Out | $T_X$ $f_{ch}$ | – | 3.879 | – | kHz |
| Absolute Gain | $R_X$: $V_{in}$ = –20 dBV<br>$T_X$: $V_{in}$ = –10 dBV, Limiter disabled | $R_X$ Audio In<br>$T_X$ In | E Out<br>$T_X$ Out | AV | –4.0<br>–4.0 | 0<br>0 | 4.0<br>4.0 | dB |
| Pass Band Ripple | $R_X$ + $T_X$ Path – 1.0 µF from $T_X$ Out to $R_X$ Audio In, $f_{in}$ = low corner frequency to high corner frequency | C In | E Out | Ripple | – | 2.0 | – | dB |
| Scrambler Modulation Frequency | $R_X$: 100 mV (–20 dBV)<br>$T_X$: 316 mV (–10 dBV) | $R_X$ Audio In<br>C In | E Out<br>$T_X$ Out | $f_{mod}$ | 4.119 | 4.129 | 4.139 | kHz |
| Group Delay | $R_X$ + $T_X$ Path – 1.0 µF from $T_X$ Out to $R_X$ Audio In, $f_{in}$ = 1.0 kHz | C In | E Out | GD | – | 1.0 | – | ms |
| | $f_{in}$ = low corner frequency to high corner frequency | C In | E Out | GD | – | 4.0 | – | |
| Carrier Breakthrough | $R_X$ + $T_X$ Path – 1.0 µF from $T_X$ Out to $R_X$ Audio In | C In | E Out | CBT | – | –60 | – | dB |
| Baseband Breakthrough | $R_X$ + $T_X$ Path – 1.0 µF from $T_X$ Out to $R_X$ Audio In, $f_{in}$ = 1.0 kHz, $f_{meas}$ = 3.192 kHz | C In | E Out | BBT | – | –50 | – | dB |

**NOTE:** 1. The filter specification is based on a 10.24 MHz 2nd LO, and a switched–capacitor (SC) filter counter divider ratio of 31. If other 2nd LO frequencies and/or SC filter counter divider ratios are used, the filter corner frequency will be proportional to the resulting SC filter clock frequency.

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_x$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **MIC AMP** ($f_{in}$ = 1.0 kHz, External resistors set to gain of 1) | | | | | | | | |
| Open Loop Gain | – | $T_x$ In | Amp Out | AVOL | – | 100,000 | – | V/V |
| Gain Bandwidth | – | $T_x$ In | Amp Out | GBW | – | 100 | – | kHz |
| Maximum Output Swing | $R_L$ = 10 kΩ | $T_x$ In | Amp Out | $V_{Omax}$ | – | 2.8 | – | Vpp |
| **LOW BATTERY DETECT** | | | | | | | | |
| Average Threshold Voltage Before Electronic Adjustment | $V_{CC}$ = 3.6 V, $V_{ref}$_Adj = (0111). Take average of rising and falling threshold | $Ref_1$ $Ref_2$ | $BD_1$ Out $BD_2$ Out | $VT_i$ | 1.36 | 1.5 | 1.64 | V |
| Average Threshold Voltage After Electronic Adjustment | $V_{CC}$ = 3.6 V, $V_{ref}$_Adj = (adjusted value). Take average of rising and falling threshold | $Ref_1$ $Ref_2$ | $BD_1$ Out $BD_2$ Out | $VT_f$ | 1.475 | 1.5 | 1.525 | V |
| Hysteresis | – | $Ref_1$ $Ref_2$ | $BD_1$ Out $BD_2$ Out | Hys | – | 4.0 | – | mV |
| Input Current | $V_{in}$ = 1.0 to 2.0 V | – | $Ref_1$ $Ref_2$ | $I_{in}$ | –50 | – | 50 | nA |
| Output High Voltage | $V_{in}$ = 2.0 V, $R_L$ = 3.9 kΩ to $V_{CC}$ | $Ref_1$ $Ref_2$ | $BD_1$ Out $BD_2$ Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in}$ = 1.0 V, $R_L$ = 3.9 kΩ to $V_{CC}$ | $Ref_1$ $Ref_2$ | $BD_1$ Out $BD_2$ Out | $V_{OL}$ | – | 0.1 | 0.4 | V |

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## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Type | Description |
|---|---|---|---|
| 1<br>2 | $LO_2$ In<br>LO2 Out | – | These pins form the PLL reference oscillator when connected to an external parallel–resonant crystal (10.24 MHz typical). The reference oscillator is also the second Local Oscillator ($LO_2$) for the RF receiver. "$LO_2$ In" may also serve as an input for an externally generated reference signal which is typically ac–coupled. |
| 3 | $V_{ag}$ | – | Internal reference voltage for switched capacitor filter section. |
| 4 | $R_X$ PD | Output | Three state voltage output of the $R_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $R_X$ PLL loop filter. It is important to minimize the line length and parasitic capacitance of this pin. |
| 5 | PLL $V_{ref}$ | – | PLL voltage regulator output pin. An internal voltage regulator provides a stable power supply voltage for the $R_X$ and $T_X$ PLL's and can also be used as a regulated supply voltage for other IC's. |
| 6 | $T_X$ PD | Output | Three state voltage output of the $T_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $T_X$ PLL loop filter. It is important to minimize the line length and parasitic capacitance of this pin. |
| 7 | Gnd PLL | Gnd | Ground pin for PLL section of IC. |
| 8 | $T_X$ VCO | Input | Transmit divide counter input which is driven by an ac–coupled external transmit loop VCO. The minimum signal level is 200 mVpp @ 60.0 MHz. This pin also functions as the test mode input for the counter tests. |
| 9<br>10<br>11 | Data<br>EN<br>Clk | Input | Microprocessor serial interface input pins for programming various counters and control functions. |
| 12 | Clk Out | Output | Microprocessor Clock Output which is derived from the 2nd LO crystal oscillator and a programmable divider. It can be used to drive a microprocessor and thereby reduce the number of crystals required in the system design. The driver has an internal resistor in series with the output which can be combined with an external capacitor to form a low pass filter to reduce radiated noise on the PCB. This output also functions as the output for the counter test modes. |
| 13 | CD Out | I/O | Dual function pin; 1) Carrier detect output (open collector with external 100 kΩ pull–up resistor. 2) Hardware interrupt input which can be used to "wake–up" from Inactive Mode. |
| 14 | $BD_1$ Out | Output | Low battery detect output #1 (open collector with external pull–up resistor). |
| 15 | DA Out | Output | Data amplifier output (open collector with internal 100 kΩ pull–up resistor). |
| 16 | $BD_2$ Out | Output | Low battery detect output #2 (open collector with external pull–up resistor). |
| 17 | $T_X$ Out | Output | $T_X$ path audio output. |
| 18 | C Cap | – | Compressor rectifier filter capacitor pin. Pull pin high through a capacitor. |
| 19 | C In | Input | Compressor input (ac–coupled). |
| 20 | Amp Out | Output | Microphone amplifier output. |
| 21 | $T_X$ In | Input | $T_X$ path input to microphone amplifier (Mic Amp) (ac–coupled). |
| 22 | DA In | Input | Data amplifier input (ac–coupled). |
| 23 | $V_{CC}$ Audio | Supply | $V_{CC}$ supply for audio section. |
| 24 | $R_X$ Audio In | Input | $R_X$ audio input (ac–coupled). |
| 25 | Det Out | Output | Audio output from FM detector. |
| 26 | RSSI | Output | Receive Signal Strength Indicator filter capacitor. |
| 27<br>28 | Q Coil<br>Lim Out | – | A quad coil or ceramic discriminator connected to these pins as part of the FM demodulator circuit. |
| 29 | $V_{CC}$ RF | Supply | $V_{CC}$ supply for RF receiver section. |
| 30<br>31 | Lim $C_2$<br>Lim $C_1$ | – | IF amplifier/limiter capacitor pins. |
| 32 | Lim In | Input | Signal input for IF amplifier/limiter. |

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**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Type | Description |
|---|---|---|---|
| 33 | SGND RF | Gnd | Ground pin for RF section of the IC. |
| 34 | $Mix_2$ In | Input | Second mixer input. |
| 35 | $Mix_2$ Out | Output | Second mixer output. |
| 36 | Gnd RF | Gnd | Ground pin for RF section of the IC. |
| 37 | $Mix_1$ Out | Output | First mixer output. |
| 38 | $Mix_1$ $In_2$ | Input | Negative phase first mixer input. |
| 39 | $Mix_1$ $In_1$ | Input | Positive phase first mixer input. |
| 40<br>41 | $LO_1$ In<br>$LO_1$ Out | – | Tank Elements for 1st LO Multivibrator Oscillator are connected to these pins. |
| 42 | $V_{cap}$ Ctrl | – | 1st LO Varactor Control Pin. |
| 43 | Gnd Audio | Gnd | Ground for audio section of the IC. |
| 44 | SA Out | Output | Speaker amplifier output. |
| 45 | SA In | Input | Speaker amplifier input (ac–coupled). |
| 46 | E Out | Output | Expandor output. |
| 47 | $E_{cap}$ | – | Expandor rectifier filter capacitor pin. Pull pin high through a capacitor. |
| 48 | E In | Input | Expandor Input. |
| 49 | Scr Out | Output | $R_x$ Scrambler Output. |
| 50 | $Ref_2$ | – | Reference voltage input for Low Battery Detect #2. |
| 51 | $Ref_1$ | – | Reference voltage input for Low Battery Detect #1. |
| 52 | $V_B$ | – | Internal half supply analog ground reference. |

### FM Receiver

The FM receiver can be used with either a quad coil or a ceramic resonator. The FM receiver and 1st LO have been designed to work for all country channels, including 25 channel U.S., without the need for any external switching circuitry (see Figure 29).

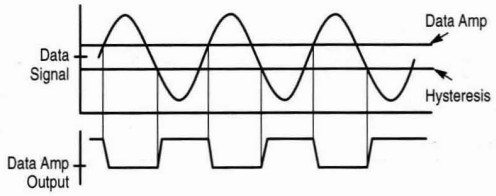
### RSSI/Carrier Detect

Connect 0.01 µF to Gnd from "RSSI" output pin to form the carrier detect filter. "CD Out" is an open collector output which requires an external 100 kΩ pull–up resistor to $V_{CC}$. The carrier detect threshold is programmable through the MPU interface.

### Data Amp Comparator

The data amp comparator is an inverting hysteresis comparator. Its open collector output has an internal 100 kΩ pull–up resistor. A band pass filter is connected between the "Det Out" pin and the "DA In" pin with component values as shown in Figure 1 (Test Circuit). The "DA In" input signal is ac–coupled.

**Figure 2. Data Amp Operation**




### Expandor/ Compressor

In Appendix B, the EIA/CCITT recommendations for measurement of the attack and decay times are defined. The curves in Figures 3 and 4 show the typical expandor and compressor output versus input responses.

**Figure 3. Expandor Typical Response**

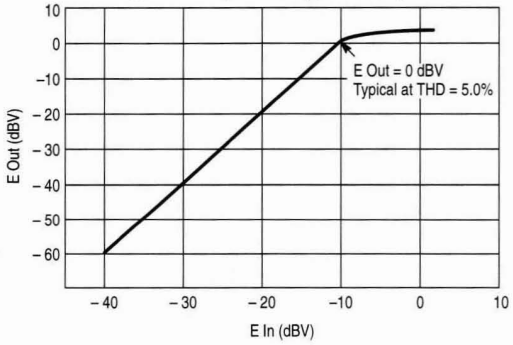
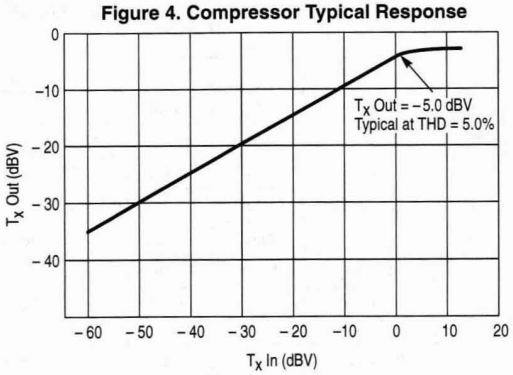



**Figure 4. Compressor Typical Response**




### $R_X$ Audio Path (LPF/$R_X$ Gain Adjust/ $R_X$ Mute/Expandor/Volume Control)

The $R_X$ Audio signal path goes from "$R_X$ Audio In" (Pin 24) to "E Out" (Pin 46). The "$R_X$ Audio In" input signal is ac coupled. AC couple between "Scr Out" and "E In" (see Figure 3).

### Speaker Amp/SP Mute

The Speaker Amp is an inverting rail–to–rail operational amplifier. The noninverting input is connected to the internal $V_B$ reference. External resistors and capacitors are used to set the gain and frequency response. The "SA In" Input is ac coupled.

### Mic Amp

The Mic Amp is an inverting rail–to–rail operational amplifier with noninverting input terminal connected to internal $V_B$ reference. External resistors and capacitors are set to the gain and frequency response. The "$T_X$ In" input is ac coupled.

### $T_X$ Audio Path (Compressor/ALC/$T_X$ Mute/ Limiter/LPF/$T_X$ Gain Adjust)

The $T_X$ Audio signal path goes from "C In" (Pin 19) to "$T_X$ Out" (Pin 17). The "C In" input signal is ac coupled. The ALC (Automatic Level Control) provides a "soft" limit to the output signal swing as the input voltage increases slowly (i.e., a sine wave is maintained). The Limiter circuit limits rapidly changing signal levels by clipping the signal peaks. The ALC and/or Limiter can be disabled through the MPU serial interface (see Figure 4).

### $T_X$ and $R_X$ Scrambler

The $T_X$ and $R_X$ signal paths each contain a frequency inversion scrambler in the MC13110. Each scrambler contains a pre–mixer low pass switched capacitor filter (SCF), a double balanced mixer and a post–mixer low pass switched capacitor filter. The scrambler function can be defeated by setting the $T_X$ or $R_X$ Scrambler Bypass bits in the control register to "1" through the MPU interface. In this mode, the mixer and the post–mixer LPF are bypassed and

only the pre–mixer LPF remains in the signal path. The SCF corner frequencies are proportional to the SCF clock. The SCF Clock Divider is programmable through the MPU interface, (SCF Clock) = F(2nd LO)/(SCF Divider Value*2). The scrambler modulation frequency is (SCF Clock)/40. Four scrambler modulation frequencies may be selected (see Figures 28 and 29).

**PLL Voltage Regulator**

The "PLL $V_{ref}$" pin is the internal supply voltage for the $R_X$ and $T_X$ PLL's. It is regulated to a nominal 2.5 V. The "$V_{CC}$ Audio" pin is the supply voltage for the internal voltage regulator. Two capacitors with 10 µF and 0.1 µF values must be connected to the "PLL $V_{ref}$" pin to filter and stabilize this regulated voltage. The "PLL $V_{ref}$" pin may be used to power other IC's as long as the total external load current does not exceed 1.0 mA. The tolerance of the regulated voltage is initially ±8.0%, but is improved to ±4.0% after the internal Bandgap voltage reference is adjusted electronically through the MPU serial interface. The voltage regulator is turned off in the Standby and Inactive modes to reduce current drain. In these modes, the "PLL $V_{ref}$" pin is internally connected to the "$V_{CC}$ Audio" pin (i.e., the power supply voltage is maintained but is now unregulated).

**Low Battery Detect**

Two external precision resistor dividers are used to set independent thresholds for two battery detect hysteresis comparators. The voltages on "$Ref_1$" and "$Ref_2$" are compared to an internally generated 1.5 V reference voltage. The tolerance of the internal reference voltage is initially ±6.0%. The Low Battery Detect threshold tolerance can be improved by adjusting a trim–pot in the external resistor divider. Alternately, the tolerance of the internal reference voltage can be improved to ±1.5% through MPU serial interface programming. The internal reference can be measured directly at the "$V_B$" pin. During final test of the telephone, the $V_B$ internal reference voltage is measured. Then, the internal reference voltage value is adjusted electronically through the MPU serial interface to achieve the desired accuracy level. The voltage reference register value should be stored in ROM during final test so that it can be reloaded each time the MC13110 IC is powered up. Low Battery Detect outputs are open collector.

**Power Supply Voltage**

This circuit is used in a cordless telephone handset and base unit. The handset is battery powered and can operate on three NiCad cells or on 5.0 V supply.

**PLL Frequency Synthesizer General Description**

Figure 5 shows a simplified block diagram of the programmable universal dual phase locked loop (PLL). This dual PLL is fully programmable through the MCU serial interface and supports most country channel frequencies including USA (25 ch), Spain, Australia, Korea, New Zealand, U. K., Netherlands, France, and China.

The 2nd local oscillator and reference divider provide the reference frequency for the receive ($R_X$) and transmit ($T_X$) PLL loops. The programmed divider value for the reference divider is selected based on the crystal frequency and the desired $R_X$ and $T_X$ reference frequency values. Additional divide by 25 and divide by 4 blocks are provided to allow for generation of the 1.0 kHz and 6.25 kHz reference frequencies required for the U. K. The 14–bit $T_X$ counter is programmed for the desired transmit channel frequency. The 14–bit $R_X$ counter is programmed for the desired first local oscillator frequency. All counters power up in the proper default state for USA channel #21 (channel #6 for FCC 10 channel band) and for a 10.24 MHz reference frequency crystal. Internal fixed capacitors can be connected to the tank circuit of the 1st LO through microprocessor control to extend the sensitivity of the 1st LO for U.S. 25 channel operation.

**PLL I/O Pin Specifications**

The 2nd LO, $R_X$ and $T_X$ PLL's, and MPU serial interface are powered by the internal voltage regulator at the "PLL $V_{ref}$" pin. The "PLL $V_{ref}$" pin is the output of a voltage regulator which is powered from the "$V_{CC}$ Audio" power supply pin and is regulated by an internal bandgap voltage reference. Therefore, the maximum input and output levels for most PLL I/O pins ($LO_2$ In, $LO_2$ Out, $R_X$ PD, $T_X$ PD, $T_X$ VCO) is the regulated voltage at the "PLL $V_{ref}$" pin. The ESD protection diodes on these pins are also connected to "PLL $V_{ref}$". Internal level shift buffers are provided for the pins (Data, Clk, EN, Clk Out) which connect directly to the microprocessor. The maximum input and output levels for these pins is $V_{CC}$. Figure 6 shows a simplified schematic of the I/O pins.

**Figure 5. Dual PLL Simplified Block Diagram**

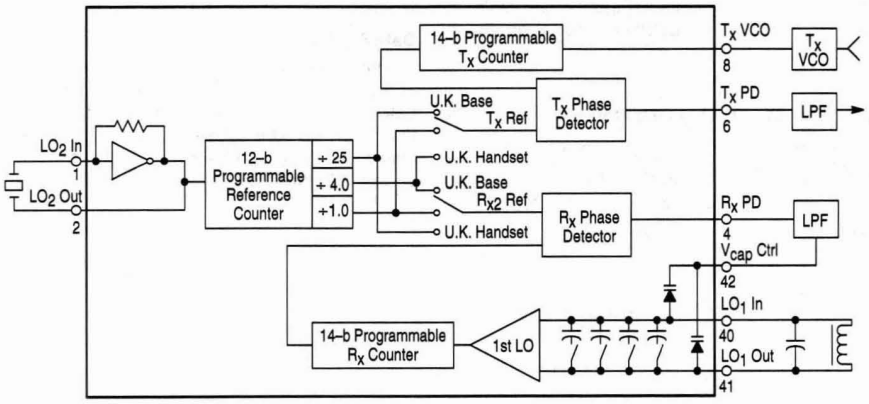
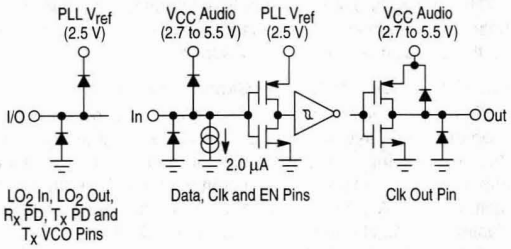


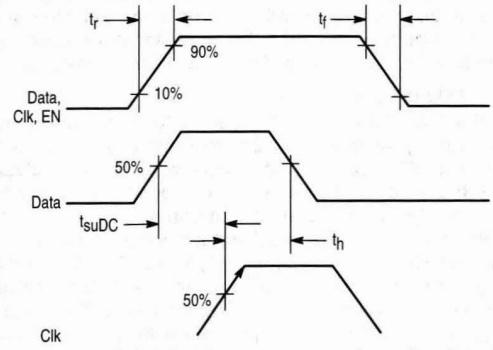
**Figure 6. PLL I/O Pin Simplified Schematics**


PLL Vref (2.5 V)
VCC Audio (2.7 to 5.5 V)
PLL Vref (2.5 V)
VCC Audio (2.7 to 5.5 V)
I/O
In
2.0 µA
Out
LO2 In, LO2 Out, Rx PD, Tx PD and Tx VCO Pins
Data, Clk and EN Pins
Clk Out Pin

### Microprocessor Serial Interface

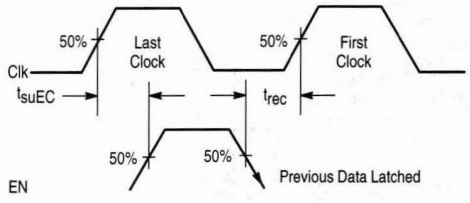
The "Data", "Clk", and "EN" pins provide an MPU serial interface for programming the reference counters, the transmit and receive channel divider counters, the switched capacitor filter clock counter, and various control functions. The "Data" and "Clk" pins are used to load data into the shift register. Figure 7 shows the timing required on the "Data" and "Clk" pins. Data is clocked into the shift register on positive clock transitions.

**Figure 7. Data and Clock Timing Requirement**



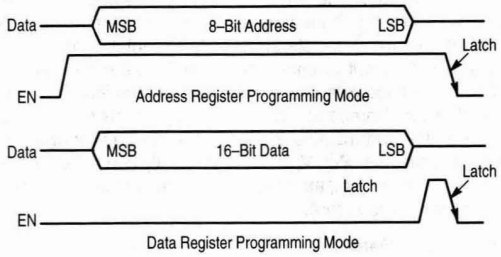

After data is loaded into the shift register, the data is latched into the appropriate latch register using the "EN" pin. This is done in two steps. First, an 8–bit address is loaded into the shift register and latched into the 8–bit address latch register. Then, up to 16–bits of data is loaded into the shift register and latched into the data latch register specified by the address that was previously loaded. Figure 5 shows the timing required on the EN pin. Latching occurs on the negative EN transition.

**Figure 8. Enable Timing Requirement**



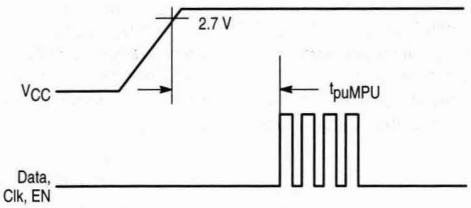

The state of the EN pin when clocking data into the shift register determines whether the data is latched into the address register or a data register. Figure 9 shows the address and data programming diagrams. In the data programming mode, there must not be any clock transitions when "EN" is high. The clock can be in a high state (default high) or a low state (default low) but must not have any transitions during the "EN" high state. The convention in these figures is that latch bits to the left are loaded into the shift register first.

**Figure 9. Microprocessor Interface Programming Mode Diagrams**




The MPU serial interface is fully operational within 100 µs after the power supply has reached its minimum level during power–up (see Figure 10). The MPU Interface shift registers and data latches are operational in all four power saving modes; Inactive, Standby, $R_X$, and Active Modes. Data can be loaded into the shift registers and latched into the latch registers in any of the operating modes.

**Figure 10. Microprocessor Serial Interface Power–Up Delay**




### Data Registers

Figure 11 shows shows the data latch registers and addresses which are used to select each of these registers. Latch bits to the left (MSB) are loaded into the shift register first. The LSB bit must always be the last bit loaded into the shift register. Bits preceeding the register must be "0's" as shown in Figure 11.

**Figure 11. Microprocessor Interface Data Latch Registers**

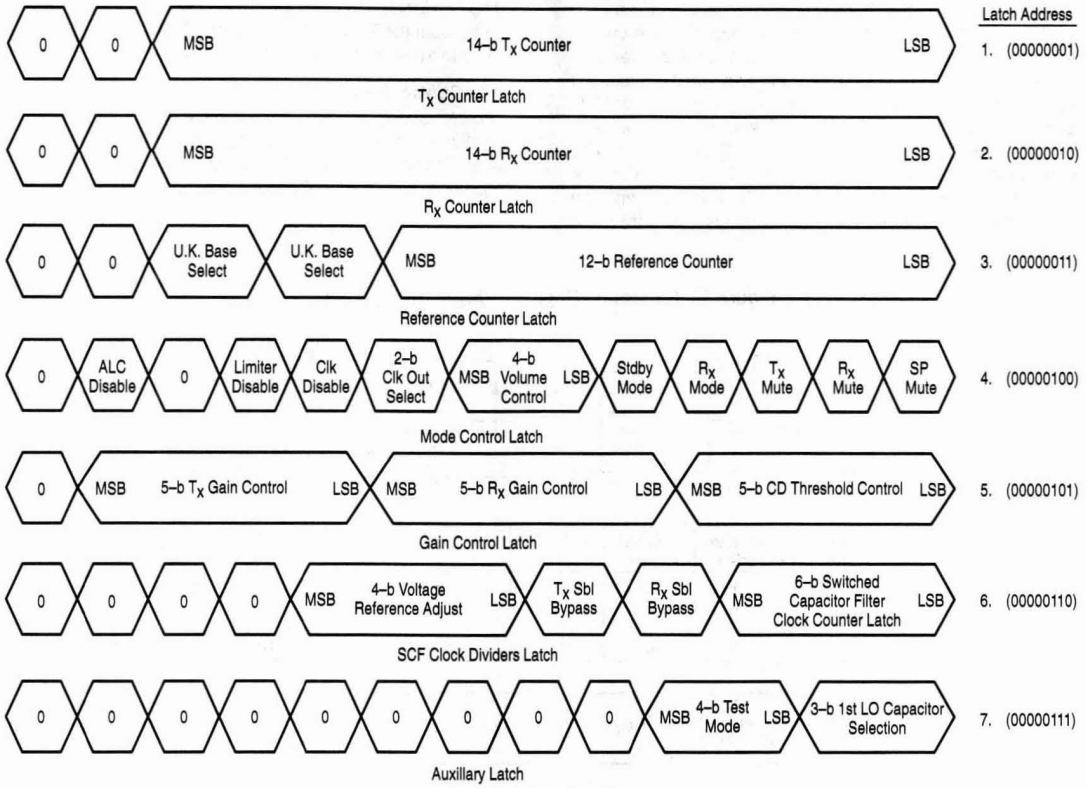

Latch Address
0 0 MSB 14–b Tx Counter LSB
1. (00000001)
Tx Counter Latch
0 0 MSB 14–b Rx Counter LSB
2. (00000010)
Rx Counter Latch
0 0 U.K. Base Select U.K. Base Select MSB 12–b Reference Counter LSB
3. (00000011)
Reference Counter Latch
0 ALC Disable 0 Limiter Disable Clk Disable 2–b Clk Out Select MSB 4–b Volume Control LSB Stdby Mode Rx Mode Tx Mute Rx Mute SP Mute
4. (00000100)
Mode Control Latch
0 MSB 5–b Tx Gain Control LSB MSB 5–b Rx Gain Control LSB MSB 5–b CD Threshold Control LSB
5. (00000101)
Gain Control Latch
0 0 0 0 MSB 4–b Voltage Reference Adjust LSB Tx Sbl Bypass Rx Sbl Bypass MSB 6–b Switched Capacitor Filter Clock Counter Latch LSB
6. (00000110)
SCF Clock Dividers Latch
0 0 0 0 0 0 0 0 0 MSB 4–b Test Mode LSB 3–b 1st LO Capacitor Selection
7. (00000111)
Auxillary Latch

**Figure 12. Reference Frequency and Reference Divider Values**

| Crystal Frequency | Reference Divider Value | U.K. Base/ Handset Divider | Reference Frequency | SC Filter Clock Divider | SC Filter Clock Frequency | Scrambler Modulation Divider | Scrambler Modulation Frequency |
|---|---|---|---|---|---|---|---|
| 10.24 MHz | 2048 | 1.0 | 5.0 kHz | 31 | 165.16 kHz | 40 | 4.129 kHz |
| 10.24 MHz | 1024 | 4.0 | 2.5 kHz | 31 | 165.16 kHz | 40 | 4.129 kHz |
| 11.15 MHz | 2230 | 1.0 | 5.0 kHz | 34 | 163.97 kHz | 40 | 4.099 kHz |
| 12.00 MHz | 2400 | 1.0 | 5.0 kHz | 36 | 166.67 kHz | 40 | 4.167 kHz |
| 11.15 MHz | 1784 | 1.0 | 6.25 kHz | 34 | 163.97 kHz | 40 | 4.099 kHz |
| 11.15 MHz | 446 | 4.0 | 6.25 kHz | 34 | 163.97 kHz | 40 | 4.099 kHz |
| 11.15 MHz | 446 | 25 | 1.0 kHz | 34 | 163.97 kHz | 40 | 4.099 kHz |

### Reference Frequency Selection

The "$LO_2$ In" and "$LO_2$ Out" pins form a reference oscillator when connected to an external parallel–resonant crystal. The reference oscillator is also the second local oscillator for the RF Receiver. Figure 12 shows the relationship between different crystal frequencies and reference frequencies for cordless phone applications in various countries. "$LO_2$ In" may also serve as an input for an externally generated reference signal which is ac–coupled. The switched capacitor filter 6–bit programmable counter must be programmed for the crystal frequency that is selected since this clock is derived from the crystal frequency and must be held constant regardless of the crystal that is selected. The actual switched capacitor clock divider ratio is twice the programmed divider ratio since there is a fixed divide by 2.0 after the programmable counter. The scrambler mixer modulation frequency is the switched capacitor clock divided by 40.

### Reference Counter

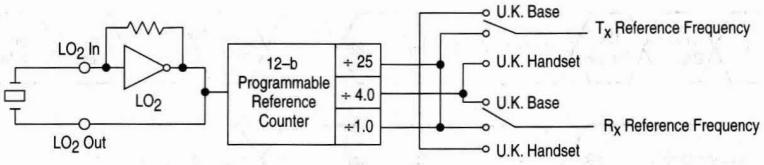
Figure 13 shows how the reference frequencies for the $R_X$ and $T_X$ loops are generated. All countries except the U.K.

require that the $T_X$ and $R_X$ reference frequencies be identical. In this case, set "U.K. Base Select" and "U.K. Handset Select" bits to "0". Then the fixed divider is set to "1" and the $T_X$ and $R_X$ reference frequencies will be equal to the crystal oscillator frequency divided by the programmable reference counter value. The U.K. is a special case which requires a different reference frequency value for $T_X$ and $R_X$. For U.K. base operation, set "U.K. Base Select" to "1". For U.K. handset operation, set "U.K. Handset Select" to "1".The Netherlands is also a special case since a 2.5 kHz reference frequency is used for both the $T_X$ and $R_X$ reference and the total divider value required is 4096 which is larger than the maximum divide value available from the 12–bit reference divider (4095). In this case, set "U.K. Base Select" to "1" and set "U.K. Handset Select" to "1". This will give a fixed divide by 4 for both the $T_X$ and $R_X$ reference. Then set the reference divider to 1024 to get a total divider of 4096.

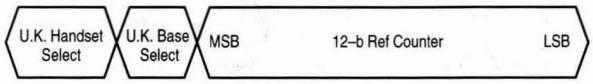
### Mode Control Register

Power saving modes, mutes, disables, volume control, and microprocessor clock output frequency are all set by the Mode Control Register. Operation of the Mode Control Register is explained in Figures 14 through 21.

**Figure 13. Reference Register Programming Mode**




| U.K. Handset Select | U.K. Base Select | $T_X$ Divider Value | $R_X$ Divider Value | Application |
|---|---|---|---|---|
| 0 | 0 | 1.0 | 1.0 | All but U.K. and Netherlands |
| 0 | 1 | 25 | 4.0 | U.K. Base Set |
| 1 | 0 | 4.0 | 25 | U.K. Hand Set |
| 1 | 1 | 4.0 | 4.0 | Netherlands Base and Hand Set |




14–Bit Reference Counter Latch

8

**Figure 14. Mode Control Register Bits**

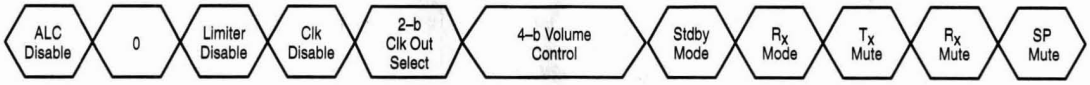



**Figure 15. Mute and Disable Control Bit Descriptions**

| | | |
|---|---|---|
| ALC Disable | 1<br>0 | Automatic Level Control Disabled<br>Normal Operation |
| Limiter Disable | 1<br>0 | Limiter Disabled<br>Normal Operation |
| Clock Disable | 1<br>0 | MPU Clock Output Disabled<br>Normal Operation |
| $T_X$ Mute | 1<br>0 | Transmit Channel Muted<br>Normal Operation |
| $R_X$ Mute | 1<br>0 | Receive Channel Muted<br>Normal Operation |
| SP Mute | 1<br>0 | Speaker Amp Muted<br>Normal Operation |

### Power Saving Operating Modes

When the MC13110 is used in a handset, it is important to conserve power in order to prolong battery life. There are five modes of operation; Active, $R_X$, Standby, Interrupt, and Inactive. In Active mode, all circuit blocks are powered. In $R_X$ mode, all circuitry is powered down except for those circuit sections needed to receive a transmission from the base. In the Standby and Interrupt Modes, all circuitry is powered down except for the circuitry needed to provide the clock output for the microprocessor. In Inactive Mode, all circuitry is powered down except the MPU interface. Latch memory is maintained in all modes. Figure 16 shows the control register bit values for selection of each power saving mode and Figure 17 shows the circuit blocks which are powered in each of these operating modes.

**Figure 16. Power Saving Mode Selection**

| Stdby Mode Bit | $R_X$ Mode Bit | "CD Out/ Hardware Interrupt" Pin | Mode |
|---|---|---|---|
| 0 | 0 | X | Active |
| 0 | 1 | X | $R_X$ |
| 1 | 0 | X | Standby |
| 1 | 1 | 1 or High Impedance | Inactive |
| 1 | 1 | 0 | Interrupt |

**Figure 17. Power Saving Modes**

| Circuit Blocks | Active | $R_X$ | Standby | Inactive |
|---|---|---|---|---|
| "PLL $V_{ref}$" Regulated Voltage | X | X | X[1] | X[1] |
| MPU Interface | X | X | X | X |
| 2nd LO Oscillator | X | X | X | |
| MPU Clock Output | X | X | X | |
| RF Receiver and 1st LO VCO | X | X | | |
| $R_X$ PLL | X | X | | |
| Carrier Detect | X | X | | |
| Data Amp | X | X | | |
| Low Battery Detect | X | X | | |
| $T_X$ PLL | X | | | |
| $R_X$ and $T_X$ Audio Paths | X | | | |

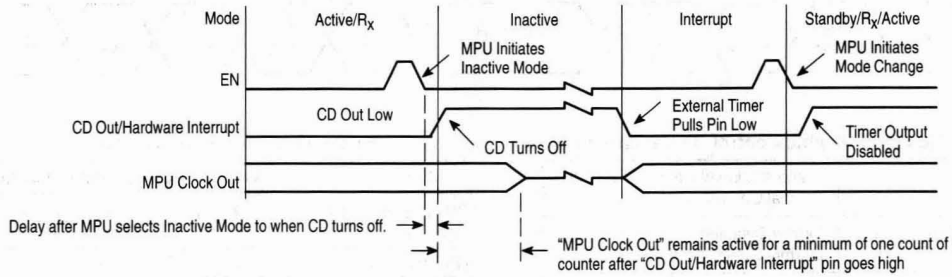
**NOTE:** In Standby and Inactive Modes, "PLL $V_{ref}$" remains powered but is not regulated. It will fluctuate with $V_{CC}$.

### Inactive Mode Operation and Hardware Interrupt

In some handset applications it may be desirable to power down all circuitry including the microprocessor (MPU). First put the combo IC into the Inactive mode, which turns off the MPU Clock Output (see Figure 18), and then disable the microprocessor. In order to give the MPU adequate time to power down, the MPU Clock output remains active for a minimum of one reference counter cycle (about 200 µs) after the command is given to switch into the "Inactive" mode. An external timing circuit should be used to initiate the turn–on sequence. The "CD Out" pin has a dual function. In the Active and $R_X$ modes it performs the carrier detect function. In the Standby and Inactive modes the carrier detect circuit is disabled and the "CD Out" pin is in a "High" state due to the external pull–up resistor. In the Inactive mode, the "CD Out" pin is the input for the hardware interrupt function. When the "CD Out" pin is pulled "low" by the external timing circuit, the combo IC switches from the Inactive to the Interrupt mode thereby turning on the MPU Clock Output. The MPU can then resume control of the combo IC. The "CD Out" pin must remain low until the MPU changes the operating mode from Interrupt to Standby, Active or $R_X$ modes.

8

**Figure 18. Hardware Interrupt Operation**


Mode
Active/Rx
Inactive
Interrupt
Standby/Rx/Active
MPU Initiates Inactive Mode
MPU Initiates Mode Change
EN
CD Out Low
External Timer Pulls Pin Low
CD Out/Hardware Interrupt
CD Turns Off
Timer Output Disabled
MPU Clock Out
Delay after MPU selects Inactive Mode to when CD turns off.
"MPU Clock Out" remains active for a minimum of one count of reference counter after "CD Out/Hardware Interrupt" pin goes high

### MPU "Clk Out" Divider Programming

This pin is a clock output which is derived from the crystal oscillator (2nd local oscillator). It can be used to drive a microprocessor and thereby reduce the number of crystals required. Figure 19 shows the relationship between the crystal frequency and the clock output for different divider values. Figure 20 shows the "Clk Out" register bit values.

**Figure 19. Clock Output Values**

| Crystal Frequency | Clock Output Divider | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| 10.24 MHz | 5.120 MHz | 3.413 MHz | 2.560 MHz | 2.048 MHz |
| 11.15 MHz | 5.575 MHz | 3.717 MHz | 2.788 MHz | 2.230 MHz |
| 12.00 MHz | 6.000 MHz | 4.000 MHz | 3.000 MHz | 2.400 MHz |

### MPU "Clk Out" Radiated Noise on Circuit Board

The clock line running between the MC13110 and the microprocessor has the potential to radiate noise which can cause problems in the system especially if the clock is a square wave digital signal with large high frequency harmonics. In order to minimize radiated noise, a 1.0 kΩ resistor is included on–chip in series with the "Clk Out" output driver. A small capacitor can be connected to the "Clk Out" line on the PCB to form a single pole low pass filter. This filter will significantly reduce noise radiated from the "Clk Out" line.

### Volume Control Programming

The volume control adjustable gain block can be programmed in 2.0 dB gain steps from –14 dB to +16 dB. The power–up default value is 0 dB. (See Figure 21.)

**Figure 20. Clock Output Divider**

| Clk Out Bit #1 | Clk Out Bit #0 | Clk Out Divider Value |
|---|---|---|
| 0 | 0 | 2 |
| 0 | 1 | 3 |
| 1 | 0 | 4 |
| 1 | 1 | 5 |

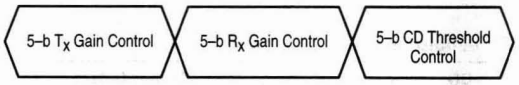
**Figure 21. Volume Control**

| Volume Control Bit #3 | Volume Control Bit #2 | Volume Control Bit #1 | Volume Control Bit #0 | Volume Control # | Gain/Attenuation Amount |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | –14 dB |
| 0 | 0 | 0 | 1 | 1 | –12 dB |
| 0 | 0 | 1 | 0 | 2 | –10 dB |
| 0 | 0 | 1 | 1 | 3 | –8.0 dB |
| 0 | 1 | 0 | 0 | 4 | –6.0 dB |
| 0 | 1 | 0 | 1 | 5 | –4.0 dB |
| 0 | 1 | 1 | 0 | 6 | –2.0 dB |
| 0 | 1 | 1 | 1 | 7 | 0 dB |
| 1 | 0 | 0 | 0 | 8 | 2.0 dB |
| 1 | 0 | 0 | 1 | 9 | 4.0 dB |
| 1 | 0 | 1 | 0 | 10 | 6.0 dB |
| 1 | 0 | 1 | 1 | 11 | 8.0 dB |
| 1 | 1 | 0 | 0 | 12 | 10 dB |
| 1 | 1 | 0 | 1 | 13 | 12 dB |
| 1 | 1 | 1 | 0 | 14 | 14 dB |
| 1 | 1 | 1 | 1 | 15 | 16 dB |

### Gain Control Register

The gain control register contains bits which control the $T_X$ Voltage Gain, $R_X$ Voltage Gain, and Carrier Detect threshold. Operation of these latch bits are explained in Figures 22, 23 and 24.

**Figure 22. Gain Control Latch Bits**




### $T_X$ and $R_X$ Gain Programming

The $T_X$ and $R_X$ audio signal paths each have a programmable gain block. If a $T_X$ or $R_X$ voltage gain other than the nominal power–up default is desired, it can be programmed through the MPU interface. Alternately, these programmable gain blocks can be used during final test of the telephone to electronically adjust for gain tolerances in the telephone system as shown in Figure 23. In this case, the $T_X$ and $R_X$ gain register values should be stored in ROM during final test so that they can be reloaded each time the combo IC is powered up.

**Figure 23. $T_X$ and $R_X$ Gain Control**

| Gain Control Bit #4 | Gain Control Bit #3 | Gain Control Bit #2 | Gain Control Bit #1 | Gain Control Bit #0 | Gain Control # | Gain/Attenuation Amount |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | –15 dB |
| 0 | 0 | 0 | 0 | 1 | 1 | –14 dB |
| 0 | 0 | 0 | 1 | 0 | 2 | –13 dB |
| 0 | 0 | 0 | 1 | 1 | 3 | –12 dB |
| 0 | 0 | 1 | 0 | 0 | 4 | –11 dB |
| 0 | 0 | 1 | 0 | 1 | 5 | –10 dB |
| 0 | 0 | 1 | 1 | 0 | 6 | –9.0 dB |
| 0 | 0 | 1 | 1 | 1 | 7 | –8.0 dB |
| 0 | 1 | 0 | 0 | 0 | 8 | –7.0 dB |
| 0 | 1 | 0 | 0 | 1 | 9 | –6.0 dB |
| 0 | 1 | 0 | 1 | 0 | 10 | –5.0 dB |
| 0 | 1 | 0 | 1 | 1 | 11 | –4.0 dB |
| 0 | 1 | 1 | 0 | 0 | 12 | –3.0 dB |
| 0 | 1 | 1 | 0 | 1 | 13 | –2.0 dB |
| 0 | 1 | 1 | 1 | 0 | 14 | –1.0 dB |
| 0 | 1 | 1 | 1 | 1 | 15 | 0 dB |
| 1 | 0 | 0 | 0 | 0 | 16 | 1.0 dB |
| 1 | 0 | 0 | 0 | 1 | 17 | 2.0 dB |
| 1 | 0 | 0 | 1 | 0 | 18 | 3.0 dB |
| 1 | 0 | 0 | 1 | 1 | 19 | 4.0 dB |
| 1 | 0 | 1 | 0 | 0 | 20 | 5.0 dB |
| 1 | 0 | 1 | 0 | 1 | 21 | 6.0 dB |
| 1 | 0 | 1 | 1 | 0 | 22 | 7.0 dB |
| 1 | 0 | 1 | 1 | 1 | 23 | 8.0 dB |
| 1 | 1 | 0 | 0 | 0 | 24 | 9.0 dB |
| 1 | 1 | 0 | 0 | 1 | 25 | 10 dB |
| 1 | 1 | 0 | 1 | 0 | 26 | 11 dB |
| 1 | 1 | 0 | 1 | 1 | 27 | 12 dB |
| 1 | 1 | 1 | 0 | 0 | 28 | 13 dB |
| 1 | 1 | 1 | 0 | 1 | 29 | 14 dB |
| 1 | 1 | 1 | 1 | 0 | 30 | 15 dB |
| 1 | 1 | 1 | 1 | 1 | 31 | 16 dB |

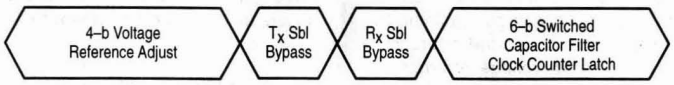
### Carrier Detect Threshold Programming

The "CD Out" pin gives an indication to the microprocessor if a carrier signal is present on the selected channel. The nominal value and tolerance of the carrier detect threshold is given in the carrier detect specification section of this document. If a different carrier detect threshold value is desired, it can be programmed through the MPU interface as shown in Figure 24. Alternately, the carrier detect threshold can be electronically adjusted during final test of the telephone to reduce the tolerance of the carrier detect threshold. This is done by measuring the threshold and then by adjusting the threshold through the MPU interface. In this case, it is necessary to store the carrier detect register value in ROM so that the CD register can be reloaded each time the combo IC is powered up.

**Figure 24. Carrier Detect Threshold Control**

| CD Bit #4 | CD Bit #3 | CD Bit #2 | CD Bit #1 | CD Bit #0 | CD Control # | Carrier Detect Threshold |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | –20 dB |
| 0 | 0 | 0 | 0 | 1 | 1 | –19 dB |
| 0 | 0 | 0 | 1 | 0 | 2 | –18 dB |
| 0 | 0 | 0 | 1 | 1 | 3 | –17 dB |
| 0 | 0 | 1 | 0 | 0 | 4 | –16 dB |
| 0 | 0 | 1 | 0 | 1 | 5 | –15 dB |
| 0 | 0 | 1 | 1 | 0 | 6 | –14 dB |
| 0 | 0 | 1 | 1 | 1 | 7 | –13 dB |
| 0 | 1 | 0 | 0 | 0 | 8 | –12 dB |
| 0 | 1 | 0 | 0 | 1 | 9 | –11 dB |
| 0 | 1 | 0 | 1 | 0 | 10 | –10 dB |
| 0 | 1 | 0 | 1 | 1 | 11 | –9.0 dB |
| 0 | 1 | 1 | 0 | 0 | 12 | –8.0 dB |
| 0 | 1 | 1 | 0 | 1 | 13 | –7.0 dB |
| 0 | 1 | 1 | 1 | 0 | 14 | –6.0 dB |
| 0 | 1 | 1 | 1 | 1 | 15 | –5.0 dB |
| 1 | 0 | 0 | 0 | 0 | 16 | –4.0 dB |
| 1 | 0 | 0 | 0 | 1 | 17 | –3.0 dB |
| 1 | 0 | 0 | 1 | 0 | 18 | –2.0 dB |
| 1 | 0 | 0 | 1 | 1 | 19 | –1.0 dB |
| 1 | 0 | 1 | 0 | 0 | 20 | 0 dB |
| 1 | 0 | 1 | 0 | 1 | 21 | 1.0 dB |
| 1 | 0 | 1 | 1 | 0 | 22 | 2.0 dB |
| 1 | 0 | 1 | 1 | 1 | 23 | 3.0 dB |
| 1 | 1 | 0 | 0 | 0 | 24 | 4.0 dB |
| 1 | 1 | 0 | 0 | 1 | 25 | 5.0 dB |
| 1 | 1 | 0 | 1 | 0 | 26 | 6.0 dB |
| 1 | 1 | 0 | 1 | 1 | 27 | 7.0 dB |
| 1 | 1 | 1 | 0 | 0 | 28 | 8.0 dB |
| 1 | 1 | 1 | 0 | 1 | 29 | 9.0 dB |
| 1 | 1 | 1 | 1 | 0 | 30 | 10 dB |
| 1 | 1 | 1 | 1 | 1 | 31 | 11 dB |

**Figure 25. Switched Capacitor Filter Clock Divider/Voltage Reference Adjust Latch Bits**




### SCF Clock Divider/Voltage Reference Adjust Register

This register controls the scrambler bypass mode, the divider value for the programmable switched capacitor filter clock divider, and the voltage reference adjust. Operation is explained in Figures 25 through 30.

**Figure 26. Bypass Mode Bit Description**

| | | |
|---|---|---|
| $T_X$ Scrambler Bypass | 1 | $T_X$ Scrambler Post–Mixer LPF and Mixer Bypassed |
| | 0 | Normal Operation with $T_X$ Scrambler |
| $R_X$ Scrambler Bypass | 1 | $R_X$ Scrambler Post–Mixer LPF and Mixer Bypassed |
| | 0 | Normal Operation $R_X$ Scrambler |

### Switched Capacitor Filter Clock Programming

A block diagram of the switched capacitor filter and scrambler modulation clock dividers is shown in Figure 27. There is a fixed divide by 2 after the programmable divider. The switched capacitor filter clock value is given by the following equation;

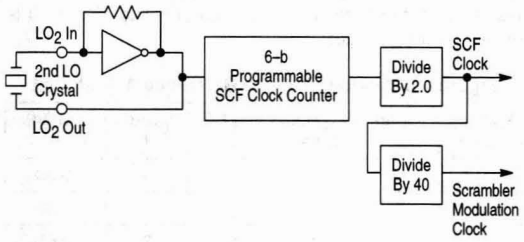
(SCF Clock) = F(2nd LO)/(SCF Divider Value * 2)

The scrambler modulation clock frequency (SMCF) is proportional to the SCF clock and is given by the following equation;

SMCF = (SCF Clock Frequency)/40

The SCF divider should be set to a value which gives a SCF Clock as close to 165.16 kHz as possible based on the 2nd LO frequency which is chosen (see Figure 12).

**Figure 27. SCF Clock and Scrambler Carrier Circuit**




### Scrambler Modulation Frequency Programming

Four different scrambler modulation frequencies may be selected by programming the SCF Clock divider as shown in Figures 28 and 29. Note that all filter corner frequencies will change proportionately with the SCF Clock and Scrambler Modulation Frequency. The power–up default SCF Clock divider value is 31.

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**Figure 28. Scrambler Modulation Frequency Programming for a 10.240 MHz 2nd LO**

| SCF Clock Divider | Total Divide Value | SCF Clock Freq. (kHz) | Scrambler Modulation Frequency (Clk/40) (kHz) | Scrambler Lower Corner Frequency (Hz) | Scrambler Upper Corner Frequency (kHz) | $R_X$ Upper (Scrambler Bypassed) Corner Frequency (kHz) | $T_X$ Upper (Scrambler Bypassed) Corner Frequency (kHz) |
|---|---|---|---|---|---|---|---|
| 29 | 58 | 176.55 | 4.414 | 267.2 | 3.902 | 4.147 | 3.955 |
| 30 | 60 | 170.67 | 4.267 | 258.3 | 3.772 | 4.008 | 3.823 |
| 31 | 62 | 165.16 | 4.129 | 250.0 | 3.650 | 3.879 | 3.700 |
| 32 | 64 | 160.00 | 4.000 | 242.2 | 3.536 | 3.758 | 3.584 |

**NOTE:** All filter corner frequencies have a tolerance of ±3%.

**Figure 29. Scrambler Modulation Frequency Programming for a 11.15 MHz 2nd LO**

| SCF Clock Divider | Total Divide Value | SCF Clock Freq. (kHz) | Scrambler Modulation Frequency (Clk/40) (kHz) | Scrambler Lower Corner Frequency (Hz) | Scrambler Upper Corner Frequency (kHz) | $R_X$ Upper (Scrambler Bypassed) Corner Frequency (kHz) | $T_X$ Upper (Scrambler Bypassed) Corner Frequency (kHz) |
|---|---|---|---|---|---|---|---|
| 32 | 64 | 174.22 | 4.355 | 263.7 | 3.850 | 4.092 | 3.903 |
| 33 | 66 | 168.94 | 4.223 | 255.7 | 3.733 | 3.968 | 3.785 |
| 34 | 68 | 163.97 | 4.099 | 248.2 | 3.624 | 3.851 | 3.673 |
| 35 | 70 | 159.29 | 3.982 | 241.1 | 3.520 | 3.741 | 3.568 |

**NOTE:** All filter corner frequencies have a tolerance of ±3%.

### Voltage Reference Adjustment

The internal 1.5 V Bandgap voltage reference provides the voltage reference for the "BD1 Out" and "BD2 Out" low battery detect circuits, the "PLL $V_{ref}$" voltage regulator, the "$V_B$" reference, and all internal analog ground references. The initial tolerance of the Bandgap voltage reference is ±6%. The tolerance of the internal reference voltage can be improved to ±1.5% through MPU serial interface programming.

During final test of the telephone, the battery detect threshold is measured. Then, the internal reference voltage value is adjusted electronically through the MPU serial interface to achieve the desired accuracy level. The voltage reference register value should be stored in ROM during final test so that it can be reloaded each time the MC13110 is powered up (see Figure 30).

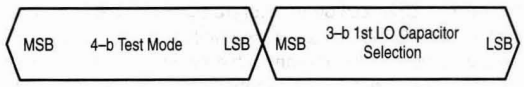
**Figure 30. Bandgap Voltage Reference Adjustment**

| $V_{ref}$ Adj. Bit #3 | $V_{ref}$ Adj. Bit #2 | $V_{ref}$ Adj. Bit #1 | $V_{ref}$ Adj. Bit #0 | $V_{ref}$ Adj. # | $V_{ref}$ Adj. Amount |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | –9.0% |
| 0 | 0 | 0 | 1 | 1 | –7.8% |
| 0 | 0 | 1 | 0 | 2 | –6.6% |
| 0 | 0 | 1 | 1 | 3 | –5.4% |
| 0 | 1 | 0 | 0 | 4 | –4.2% |
| 0 | 1 | 0 | 1 | 5 | –3.0% |
| 0 | 1 | 1 | 0 | 6 | –1.8% |
| 0 | 1 | 1 | 1 | 7 | –0.6% |
| 1 | 0 | 0 | 0 | 8 | +0.6 % |
| 1 | 0 | 0 | 1 | 9 | +1.8 % |
| 1 | 0 | 1 | 0 | 10 | +3.0 % |
| 1 | 0 | 1 | 1 | 11 | +4.2 % |
| 1 | 1 | 0 | 0 | 12 | +5.4 % |
| 1 | 1 | 0 | 1 | 13 | +6.6 % |
| 1 | 1 | 1 | 0 | 14 | +7.8 % |
| 1 | 1 | 1 | 1 | 15 | +9.0 % |

### Auxiliary Register

The auxiliary register contains a 3–bit 1st LO Capacitor Selection latch and a 4–bit Test Mode latch. Operation of these latch bits are explained in Figures 31, 32 and 34.

**Figure 31. Auxiliary Register Latch Bits**




### First Local Oscillator Programmable Selection (U.S. Applications)

There is a very large frequency difference between the minimum and maximum channel frequencies in the 25 Channel U.S. Standard.The sensitivity of the 1st LO may not be large enough to accommodate this large frequency variation. Fixed capacitors can be connected across the 1st LO tank circuit to change the 1st LO sensitivity. Internal switches and capacitors are provided to enable microprocessor control over internal fixed capacitor values. Figures 32 and 33 show the schematic representation of the 1st LO and the tank circuit. Figure 34 shows the latch control bit values for microprocessor control.

**Figure 32. First Local Oscillator Schematic**

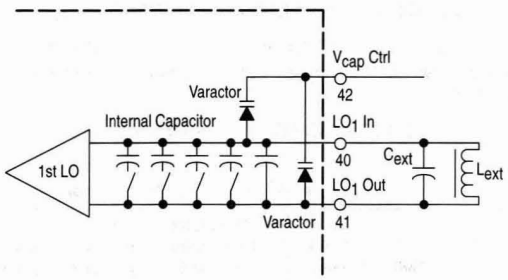


**Figure 33. First Local Oscillator Simplified Schematic**

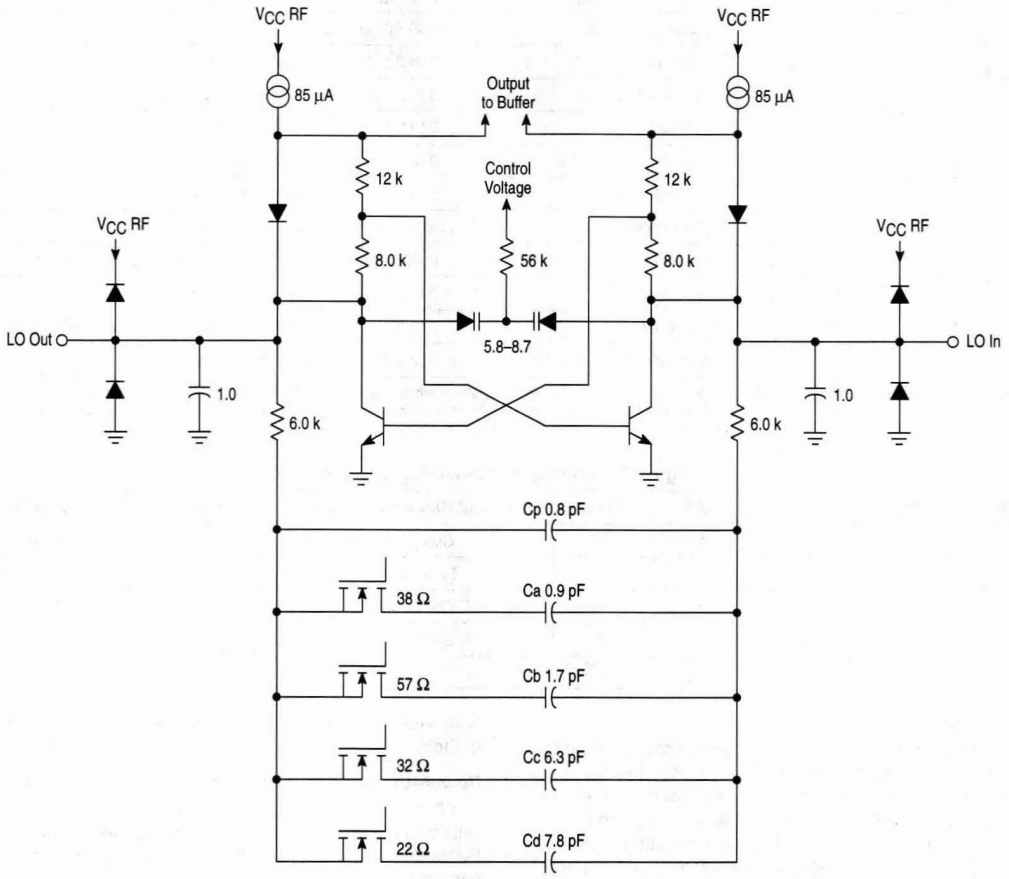



**Figure 34. First Local Oscillator Programmable Capacitor Selection for U.S. 25 Channels**

| 1st LO Cap. Bit 2 | 1st LO Cap. Bit 1 | 1st LO Cap Bit 0 | 1st LO Cap. Select | U.S. Base Chan-nels | U.S. Handset Channels | Internal Capacitor Value | Varactor Value over 0.3 to 2.5 V | Equivalent Internal Parallel Resistance at 40 MHz (kΩ) | Equivalent Internal Parallel Resistance at 51 MHz (kΩ) | External Capacitor Value | External Inductor Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1–10 | – | 0.8 pF | 5.8–8.7 pF | >1000 | >1000 | 24 pF | 0.47 µH |
| 0 | 0 | 0 | 0 | – | 1–10 | 0.8 pF | 5.8–8.7 pF | >1000 | >1000 | 33 pF | 0.47 µH |
| 0 | 0 | 1 | 1 | 11–16 | – | 2.5 pF | 5.8–8.7 pF | 35 | 21 | 24 pF | 0.47 µH |
| 0 | 1 | 0 | 2 | 17–25 | – | 1.7 pF | 5.8–8.7 pF | 100 | 60 | 24 pF | 0.47 µH |
| 0 | 1 | 1 | 3 | – | 11–16 | 8.6 pF | 5.8–8.7 pF | 6.1 | 3.8 | 33 pF | 0.47 µH |
| 1 | 0 | 0 | 4 | – | 17–25 | 7.1 pF | 5.8–8.7 pF | 8.0 | 5.0 | 33 pF | 0.47 µH |

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**Figure 35. Digital Test Mode Description**

| TM # | TM 3 | TM 2 | TM 1 | TM 0 | Counter Under Test or Test Mode Option | "$T_X$ $V_{CO}$" Input Signal | "Clk Out" Output Expected |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | Normal Operation | >200 mVpp | – |
| 1 | 0 | 0 | 0 | 1 | $R_X$ Counter, upper 6 | 0 to 2.5 V | Input Frequency/64 |
| 2 | 0 | 0 | 1 | 0 | $R_X$ Counter, lower 8 | 0 to 2.5 V | See Note Below |
| 3 | 0 | 0 | 1 | 1 | $R_X$ Prescaler | 0 to 2.5 V | Input Frequency/4 |
| 4 | 0 | 1 | 0 | 0 | $T_X$ Counter, upper 6 | 0 to 2.5 V | Input Frequency/64 |
| 5 | 0 | 1 | 0 | 1 | $T_X$ Counter, lower 8 | 0 to 2.5 V | See Note Below |
| 6 | 0 | 1 | 1 | 0 | $T_X$ Prescaler | >200 mVpp | Input Frequency/4 |
| 7 | 0 | 1 | 1 | 1 | Reference Counter | 0 to 2.5 V | Input Frequency/Reference Counter Value |
| 8 | 1 | 0 | 0 | 0 | Divide by 4, 25 | 0 to 2.5 V | Input Frequency/100 |
| 9 | 1 | 0 | 0 | 1 | SC Counter | 0 to 2.5 V | Input Frequency/SC Counter Value |
| 10 | 1 | 0 | 1 | 0 | Scrambler Modulation Counter | 0 to 2.5 V | Input Frequency/40 |

**NOTE:** To determine the correct output, look at the lower 8–bits in the $R_X$ or $T_X$ register (Divisor (7;0). If the value of the divisor is > 16, then the output divisor value is Divisor (7;2) (the upper 6–bits of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) > = 2, then output divisor value is Divisor (3;2) (bits 2 and 3 of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) < 2, then output divisor value is (Divisor (3;2) + 60).

**Figure 36. Analog Test Mode Description**

| TM # | TM 3 | TM 2 | TM 1 | TM 0 | Circuit Blocks Under Test | Input Pin | Output Pin |
|---|---|---|---|---|---|---|---|
| 11 | 1 | 0 | 1 | 1 | Compressor | C In | $T_X$ In |
| 12 | 1 | 1 | 0 | 0 | $T_X$ Scrambler | $T_X$ In | $T_X$ Out |
| 13 | 1 | 1 | 0 | 1 | ALC Gain = 10 Option | N/A | N/A |
| 14 | 1 | 1 | 1 | 0 | ALC Gain = 25 Option | N/A | N/A |
| 15 | 1 | 1 | 1 | 1 | Not Used | N/A | N/A |

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### Test Modes

Digital and analog test modes can be selected through the 4–bit Test Mode Register. In digital test mode, the "$T_X$ $V_{CO}$" input pin is multiplexed to the input of the counter under test and the output of the counter under test is multiplexed to the "Clk Out" output pin so that each counter can be individually tested. Make sure test mode bits are set to "0's" for normal operation. Digital test mode operation is described in Figure 35. During normal operation and when testing the $T_X$ Prescaler, the "$T_X$ VCO" input can be a minimum of 200 mVpp at 80 MHz and should be ac–coupled. For other test modes, input signals should be standard logic levels of 0 to 2.5 V and a maximum frequency of 16 MHz.

The analog test modes enable separate testing of the Compressor and $T_X$ Scrambler blocks as shown in Figure 36. Also, ALC Gain options can be selected through analog test modes.

### Power–Up Defaults for Control and Counter Registers

When the IC is first powered up, all latch registers are initialized to a defined state. The device is initially placed in the Rx mode with all mutes active. The reference counter is set to generate a 5.0 kHz reference frequency from a 10.24 MHz crystal. The switched capacitor filter clock counter is set properly for operation with a 10.24 MHz crystal. The scrambler bypass mode control are set for normal operation of scrambler. The $T_X$ and $R_X$ latch registers are set for USA Channel Frequency 21 (Channel 6 for previous FCC 10 Channel Band). Figure 37 shows the initial power–up states for all latch registers.

**Figure 37. Latch Register Power–Up Defaults**

| | | MSB | | | | | | | | LSB | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Register | Count | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| $T_X$ | 9966 | – | – | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| $R_X$ | 7215 | – | – | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| Ref | 2048 | – | – | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mode | N/A | – | 0 | X | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Gain | N/A | – | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 |
| SC | 31 | – | – | – | – | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| Aux | N/A | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPLICATIONS INFORMATION

### Evaluation PC Board

The PCB should be double sided with a full ground plane on one side; any leaded components are inserted on the ground plane side. This affords shielding and isolation from the circuit side of the PCB. The other side is the circuit side which has the interconnect traces and the surface mount components. In cases where cost allows, it may be benificial to use multi layer boards.

The placement of certain components specified in the application circuits is very critical. These components should be placed first and the other less critical components are fitted in last. In general, all RF paths should be kept as short as possible, ground pins should be grounded at the pins and $V_{CC}$ pins should have adequate decoupling to ground at the pins. In mixed mode systems where digital and RF/Analog circuitry are present, the $V_{EE}$ and $V_{CC}$ busses are isolated ac –wise from each other.

### Component Selection

The evaluation PC board is designed to accommodate specific components, while in some cases it is versatile enough to use components from various manufacturers and coil types. The application circuit schematics specify particular components that were used to achieve the results shown in the typical curves and tables, but alternate components should give similar results.

The MC13110 IC is capable of matching the sensitivity, IMD, adjacent channel rejection, and other performance criteria of a multi–chip analog cordless telephone system. For the most part, the same external components are used as in the multi–chip solution. In the following discussion, various parts of the system are analyzed for best peformance and cost tradeoffs. Specific recommendations are made where certain components or circuit designs offer superior performance. The system analyzed is the USA "CT–1" cordless phone.

### Input Matching/Sensitivity

The sensitivity of the IC is typically 0.56 μVrms matched with no preamp. To achieve suitable system performance, a preamp and passive duplexer must be used. In production final test, each section of the IC is separately tested to guarantee its system performance in the specific application. The preamp and duplexer yields typically –114 dBm 12 dB SINAD sensitivity performance under full duplex operation.

The duplexer is important to achieve full duplex operation without significant "de–sensing" of the receiver by the transmitter. The combination of the duplexer and preamp circuit have to attenuate the transmitter power to the receiver by over 60 dB to be effective. They do this while improving the receiver system noise figure and without giving up too much IMD intermodulation performance.

The duplexer may be a single piece unit offered by Shimida and Sansui products (designed for 10 channel CT–1 cordless phone) or a two piece solution offered by Toko (designed for 25 channel operation). The duplexer frequency response at the receiver port has a notch at the transmitter frequency band of about 35 to 40 dB with a 2.0 to 3.0 dB insertion loss at the receiver frequency band.

The preamp circuit utilizes a tuned transformer at the output side of the amplifier; this transformer is designed to bandpass filter the receiver input frequency while rejecting the transmitter frequency. The tuned preamp also improves the noise performance by reducing the bandwidth of the pass band and reducing the second stage contribution of the 1st mixer. The preamp is biased at about 1.0 mA and 3.0 Vdc which yields suitable noise figure and gain.

### Mixers

The 1st and 2nd mixers are similar in design. Both are double balanced to suppress the LO and the input frequencies to give only the sum and difference frequencies out. Typically the LO is suppressed about 40 to 60 dB. The 1st mixer may be driven either differentially or single ended. The gain of the 1st mixer has a 3.0 dB corner at 20 MHz and is used at a 10.7 MHz IF. It has an output impedance of 330 Ω and matches to a typical 10.7 MHz ceramic filter with a source and load impedance of 330 Ω. A series resistor may be used to raise the impedance for use with crystal filters which typically have an input impedance much greater than 330 Ω. The 2nd mixer input impedance is typically 3.0 kΩ; it requires an external 360 Ω parallel resistor for use with a standard 330 Ω 10.7 MHz ceramic filter. The second mixer output impedance is 1.5 kΩ making it suitable to match 455 kHz ceramic filters.

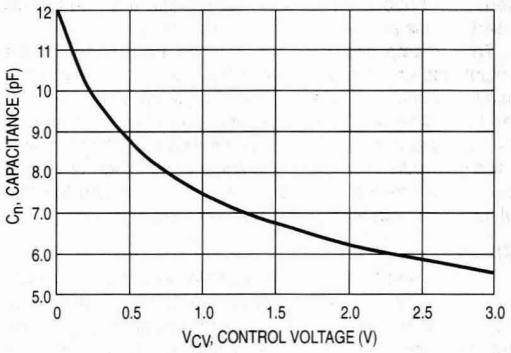
The following table is a list of typical input impedances over frequency for the 1st Mixer. $R_P$ and $C_P$ are represented in parallel form.

| Frequency (MHz) | $R_P$ (Ω) | $C_P$ (pF) |
|---|---|---|
| 20 | 977.7 | 2.44 |
| 25 | 944.3 | 2.60 |
| 30 | 948.8 | 2.65 |
| 35 | 928 | 2.55 |
| 40 | 900 | 2.51 |
| 45 | 873.4 | 2.65 |
| 50 | 859.3 | 2.72 |
| 55 | 821 | 2.72 |
| 60 | 795 | 2.74 |

### First Local Oscillator

The 1st LO is a multi–vibrator oscillator that takes an external capacitance and inductance. It is voltage controlled to an internal varactor from an external loop filter and an on–board phase–lock loop (PLL). The schematic in Figure 33 shows all the basic parasitic elements of the internal circuitry. The 1st LO internal component values have a tolerance of 15%. A typical dc bias level on the LO Input and LO Output is 0.47 Vdc. The curve in Figure 38 is the varactor control voltage range as it relates to capacitance. It represents the expected capacitance for a given control voltage of the MC13110.

**Figure 38. First Local Oscillator Varacter versus Control Voltage**




### Second Local Oscillator

The 2nd LO is a CMOS oscillator similar to that used in the MC145162. The 2nd LO is also used as the PLL reference oscillator. It is designed to utilize an external parallel resonant crystal.

### PLL Design

The 1st LO level is important, as well as the choice of the crystal for the PLL clock reference and 2nd LO. A fundamental, parallel resonant crystal specified with 7.0 to 12 pF load calibration capacitance is recommended. With load calibration capacitance too high, the crystal locks up very slowly. If the LO power is less than –10 dBm, a pull–down resistor at the 1st LO emitter (Pin 41) will increase its drive level. The LO level is primarily a function of the Colpitts capacitive voltage divider formed by the capacitors between the base to emitter and the emitter to ground.

The VCO gain factor expressed in MHz/V is indeed critical to the phase noise performance. If this curve is too steep or too sensitive to changes in control voltage, it may degrade the phase noise performance. The external VCO circuit design needs to consider the typical swing of the control voltage and the corresponding linearity of the transfer function, $\Delta f_{OSC}/\Delta V_{control}$. In general, the higher the Q of the VCO circuit inductor, the better phase noise performance.

Adjacent channel rejection and isolation between the 1st and 2nd mixers may be adversely affected due to layout problems and difficulty in getting close to the package pins with the grounds and decoupling capacitors on the RF $V_{CC}$. These system parameters must be evaluated for sensitivity to layout and external component placement.

Intermodulation and adjacent channel performance problems may also result from spurs around the 1st LO which may be caused by harmonics from the switched capacitor clock driver and too low 1st LO drive level. The clock driver operates at a frequency which is f(2nd LO)/(2 * (SCF Divider)). The harmonics are n * (f(2nd LO)), where n can be any positive integer. The current spikes of the SCF on the supply lines cause the disturbance of the 1st LO. This may be verified by observing the spurs on a spectrum analyzer while changing the clock divider value. The spur frequencies will change when the divider value is changed. The spurious sideband problem may be avoided by changing the clock divider value via software for each channel where it is a problem. Certain channels are worse than others.

The PLL alignment procedure for the application circuit is detailed in Appendix C. Refer to the MC145162 data sheet for PLL design example.

### Limiting IF Amplifiers

The limiting IF amplifier typically has about 110 dB of gain; the frequency response starts rolling off at 1.0 MHz. Decoupling capacitors should be placed close to the decoupling Pins 31 and 32 to ensure low noise and stable operation. The IF input impedance is 1.5 kΩ for a suitable match to 455 kHz ceramic filters.

### RSSI/Carrier Detect

The Received Signal Strength Indicator (RSSI) indicates the strength of the IF level and the output is proportional to the logarithm of the IF input signal magnitude. The RSSI dynamic range is typically 80 dB. Connect 0.01 µF to GND from "RSSI" output pin to form the carrier detect filter. A resistor needed to convert the RSSI current to voltage is included in the internal circuit. An internal temperature compensated reference current also improves the RSSI accuracy over temperature.

"CD Out" is an open collector output; thus, an external 100 kΩ pull–up resistor to $V_{CC}$ is recommended. The carrier detect threshold is programmable through the MPU interface.

### Quadrature Detector

The quadrature detector is coupled to the IF with an external capacitor between Pins 27 and 28; thus, the recovered signal level output is increased for a given bandwidth by increasing the capacitor. The external quadrature component may be either a LCR resonant circuit, which may be adjustable, or a ceramic resonator which is usually fixed tuned.

The bandwidth performance of the detector is controlled by the loaded Q of the LC tank circuit. The following equation defines the components which set the detector circuit's bandwidth:

$$(1)\quad R_T = Q\,X_L$$

where $R_T$ is the equivalent shunt resistance across the LC Tank. $X_L$ is the reactance of the quadrature inductor at the IF frequency ($X_L = 2\pi fL$).

Specific 455 kHz quadrature LC components are manufactured by Toko in various 5 mm, 7 mm and 10 mm shielded cans in surface mount or leaded packages. Recommended components such as, the 7 mm Toko, is used in the application circuit. When minaturization is a key constraint, a surface mount inductor and capacitor may be chosen to form a resonant LC tank with the PCB and parasitic device capacitance. The 455 kHz IF center frequency is calculated by

$$(2)\quad f_c = [2\pi\,(LC_p)^{1/2}] - 1$$

where L is the parallel tank inductor. $C_p$ is the equivalent parallel capacitance of the parallel resonant tank circuit.

The following is a design example for a detector at 455 kHz and a specific loaded Q. The loaded Q of the quadrature detector is chosen somewhat less than the Q of the IF bandpass. For an IF frequency of 455 kHz and an IF bandpass of 20 kHz, the IF bandpass Q is approximately 23; the loaded Q of the quadrature tank is chosen at 15.

Example:

Let the total external C = 180 pF. Note: the capacitance may be split between a 150 pF chip capacitor and a 5.0 to 25 pF variable capacitor; this allows for tuning to compensate for component tolerance. Since the external capacitance is much greater than the internal device and PCB parasitic capacitance, the parasitic capacitance may be neglected.

Rewrite equation (2) and solve for L:

$L = (0.159)^2/(C\ fc^2)$
$L = 678\ \mu H$ ; Thus, a standard value is chosen:
$L = 680\ \mu H$ (surface mount inductor)

The value of the total damping resistor to obtain the required loaded Q of 15 can be calculated from equation (1):

$R_T = Q(2\pi fL)$
$R_T = 15\ (2\pi)(0.455)(680) = 29.5\ k\Omega$

The internal resistance, $R_{int}$ at the quadrature tank Pin 27 is approximately 100 kΩ and is considered in determining the external resistance, $R_{ext}$ which is calculated from

$R_{ext} = ((R_T)(R_{int}))/(R_{int} - R_T)$
$R_{ext} = 41.8\ k\Omega$; Thus, choose the standard value:
$R_{ext} = 39\ k\Omega$

A ceramic discriminator is recommended for the quadrature circuit in applications where fixed tuning is desired. The ceramic discriminator and a 22 k resistor are placed from Pin 27 to $V_{CC}$. A 10 pF capacitor is placed from Pin 28 to 27 to properly drive the discriminator.

MuRata Erie has designed a resonator that is compatible with the IC. For US applications the part number is CDBM455C48. For Europe the part number is CDBM450C48. Contact Motorola Analog Marketing for performance data using muRata's parts.

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**Figure 39a. Baseset RF Applications Circuit**

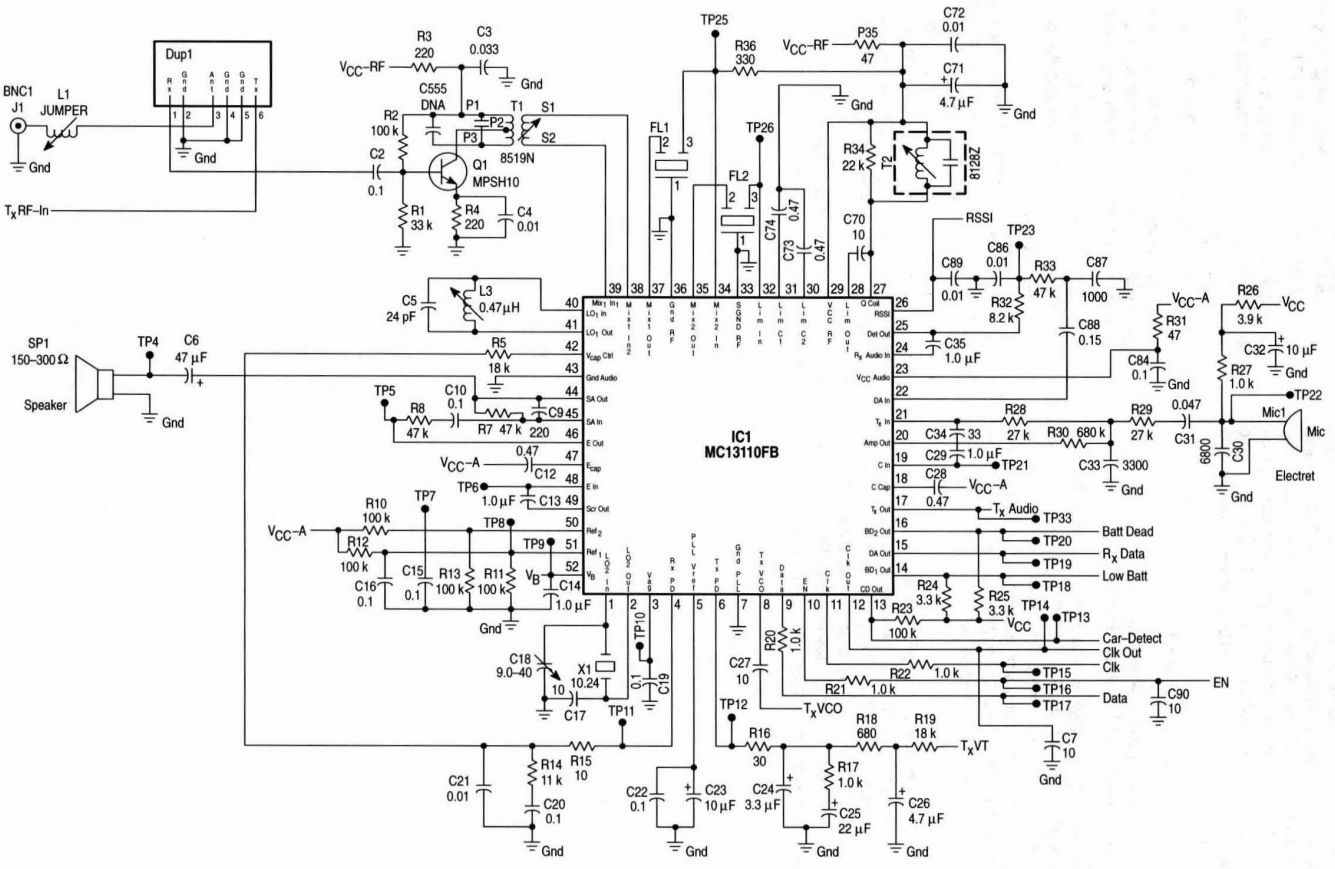
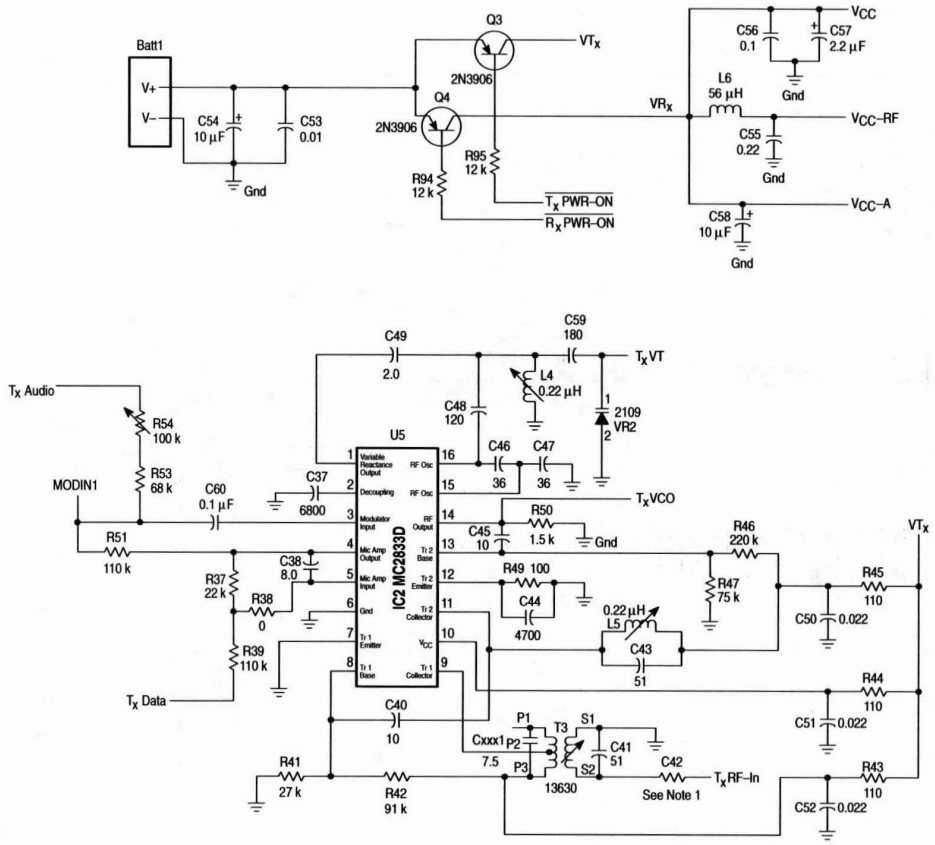
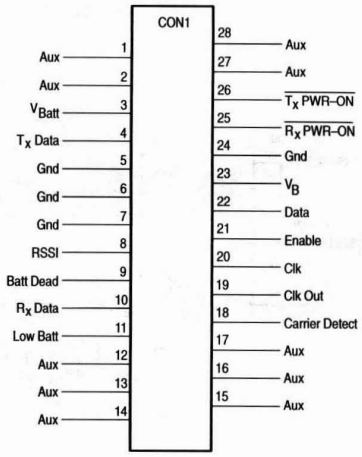


**Figure 39a. Baseset RF Applications Circuit (continued)**




NOTE 1: C42 = X42 = 51 Ω

**Figure 39b. Handset RF Applications Circuit**

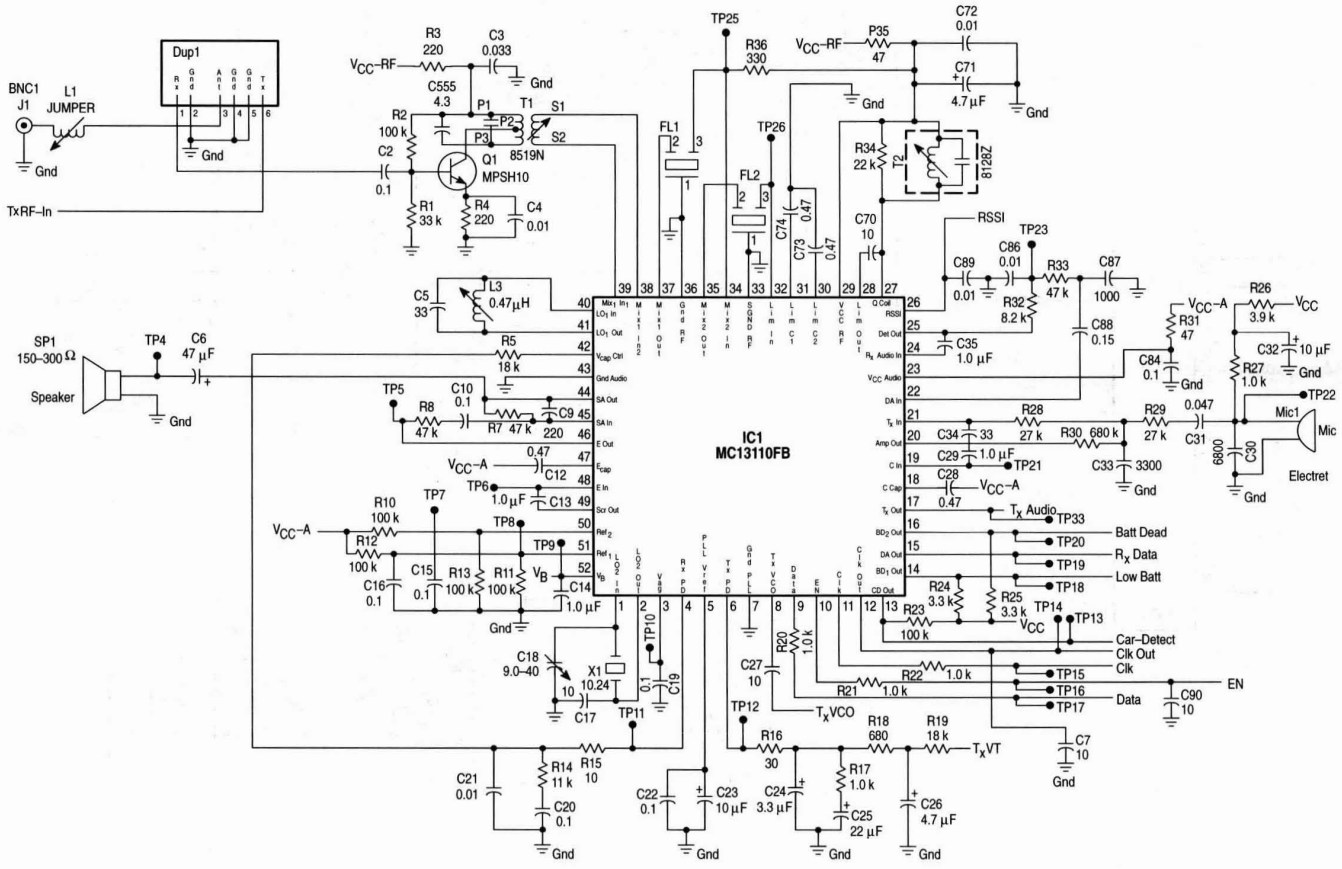
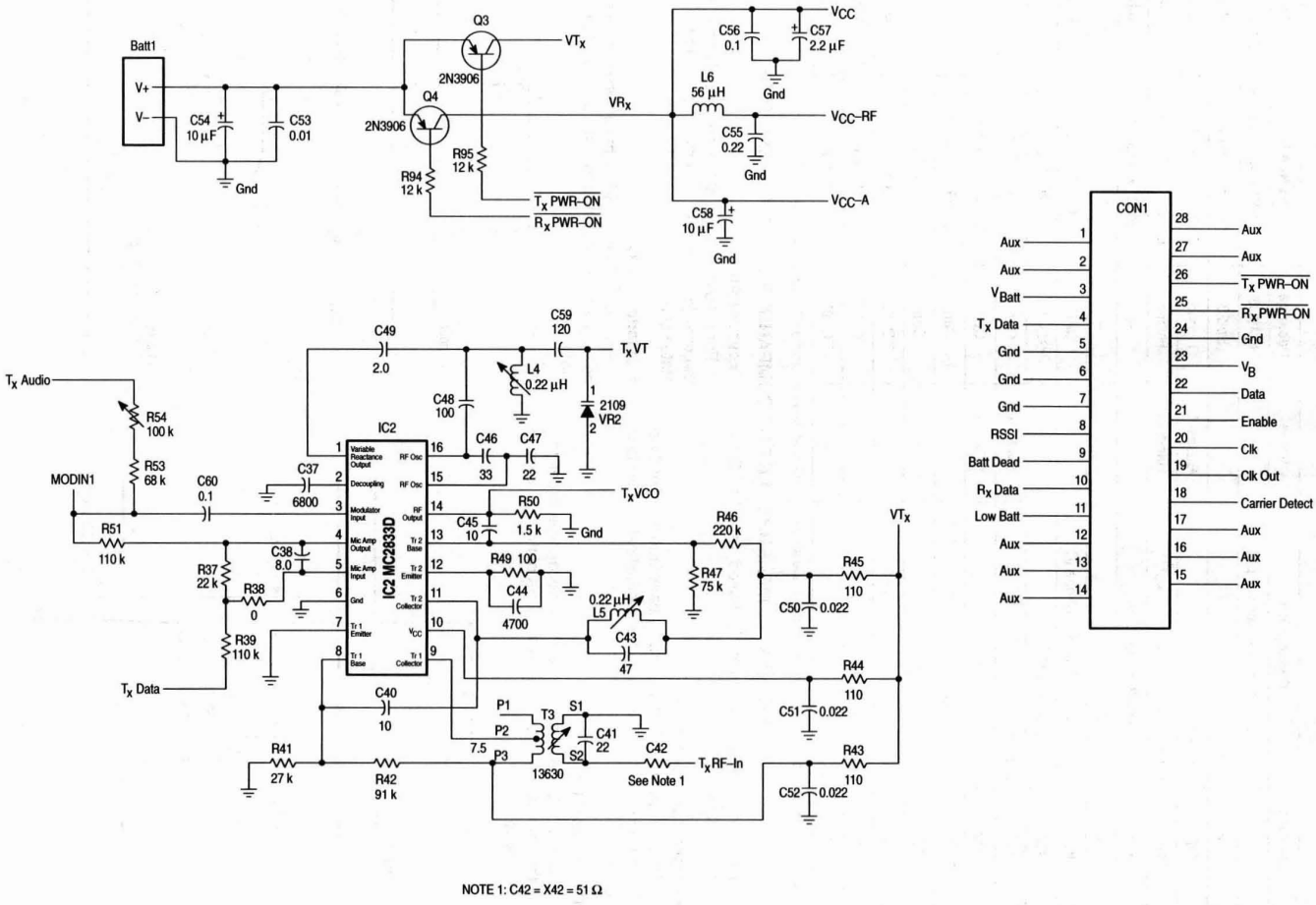


**Figure 39b. Handset RF Applications Circuit (continued)**




NOTE 1: C42 = X42 = 51 Ω

## APPENDIX B – MC13110 APPLICATION BOARD BILL OF MATERIAL (USA)

| Reference | Description | Value | Package | Part Number | Vendor |
|---|---|---|---|---|---|
| X1 | 10.24 Crystal (Load Cap <12 pF) | – | HC49US | AAL10M240000FLE10A | Standard Crystal |
| VR2 | Diode | – | Sot23 | MMBV2109LT1 | Motorola |
| DUP1 | Duplexer (25 Channel) | Baseset | Hybrid | DPX1035 75B–153B | Sumida |
| DUP1 | Duplexer (25 Channel) | Handset | Hybrid | DPX1035 75B–154B | Sumida |
| FL1 | 10.7 MHz Filter (Red Dot) | – | – | SFE10.7MS2–A | muRata |
| FL2 | 455 kHz Filter | – | – | CFU455E2 | muRata |
| IC1 | Universal Cordless Telephone IC | – | QFP | MC13110FB | Motorola |
| IC2 | FM Transmitter IC | – | SO–16 | MC2833D | Motorola |
| L3 | Inductor | 0.47 µH | Can | 292SNS–T1370Z | Toko |
| L4/L5 | Inductor | 0.22 µH | Can | 292SNS–T1368Z | Toko |
| T1/T3 | Transformer | – | Can | 600GCS–8519N | Toko |
| T2 | Quadrature Coil | – | Can | 7MCS–8128Z | Toko |
| Q1 | Transistor | – | TO–92 | MPSH10 | Motorola |
| Q3 | Transistor | – | TO–92 | 2N3906 | Motorola |
| Q4 | Transistor | – | TO–92 | 2N3906 | Motorola |

**NOTE:** Components for the Handset and Baseset are the same, except where noted on the Bill of Material and Schematic.

## APPENDIX C – MEASUREMENT OF COMPANDOR ATTACK/DECAY TIME

This measurement definition is based on EIA/CCITT recommendations.

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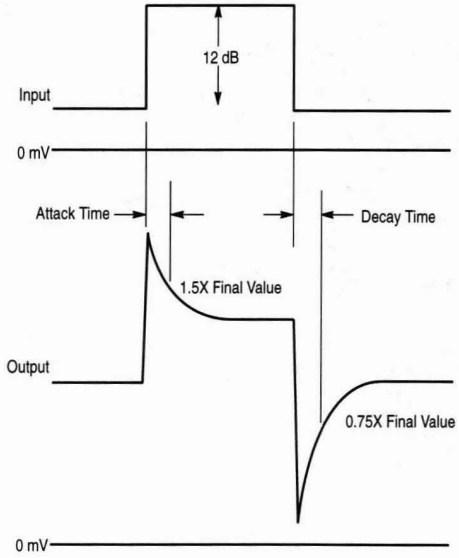
### Compressor Attack Time

For a 12 dB step up at the input, attack time is defined as the time for the output to settle to 1.5X of the final steady state value.

### Compressor Decay Time

For a 12 dB step down at the input, decay time is defined as the time for the input to settle to 0.75X of the final steady state value.

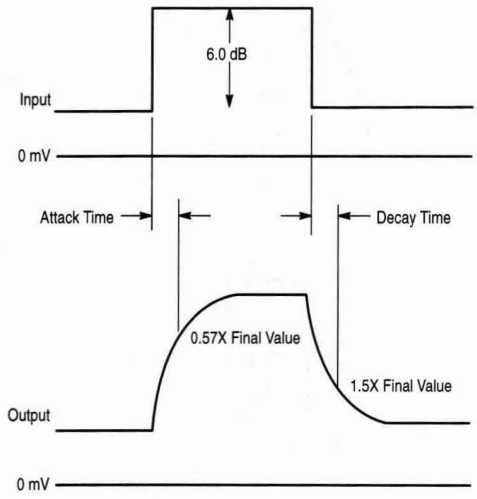



### Expandor Attack

For a 6.0 dB step up at the input, attack time is defined as the time for the output to settle to 0.57X of the final steady state value.

### Expandor Decay

For a 6.0 dB step down at the input, decay time is defined as the time for the output to settle to 1.5X of the final steady state value.



MOTOROLA

# Universal Cordless Telephone Subsystem IC

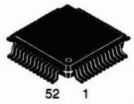
# MC13111

**UNIVERSAL CT–1 SUBSYSTEM INTEGRATED CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13111 integrates several of the functions required for a cordless telephone into a single integrated circuit. This significantly reduces component count, board space requirements, external adjustments, and lowers overall costs. It is designed for use in both the handset and the base.

- Dual Conversion FM Receiver
  - Complete Dual Conversion Receiver – Antenna In to Audio Out 80 MHz Maximum Carrier Frequency
  - RSSI Output
  - Carrier Detect Output with Programmable Threshold
  - Comparator for Data Recovery
  - Operates with Either a Quad Coil or Ceramic Discriminator
- Compander
  - Expandor Includes Mute, Digital Volume Control, Speaker Driver, 3.5 kHz Low Pass Filter, and Programmable Gain Block
  - Compressor Includes Mute, 3.5 kHz Low Pass Filter, Limiter, and Programmable Gain Block
- Dual Universal Programmable PLL
  - Supports New 25 Channel U.S. Standard with No External Switches
  - Universal Design for Domestic and Foreign CT–1 Standards
  - Digitally Controlled Via a Serial Interface Port
  - Receive Side Includes 1st LO VCO, Phase Detector, and 14–Bit Programmable Counter and 2nd LO with 12–Bit Counter
  - Transmit Section Contains Phase Detector and 14–Bit Counter
  - MPU Clock Outputs Eliminates Need for MPU Crystal
- Supply Voltage Monitor
  - Provides Two Levels of Monitoring with Separate Outputs
  - Separate, Adjustable Trip Points
- Programmable Corner Frequency Selection
- MC13111 is Pin–for–Pin Compatible with MC13110
- 2.7 to 5.5 V Operation with One–Third the Power Consumption of Competing Devices
- AN1575: Refer to this Application Note for a List of the "Worldwide Cordless Telephone Frequencies" (List can also be found in Chapter 8 Addendum of DL128 Data Book)

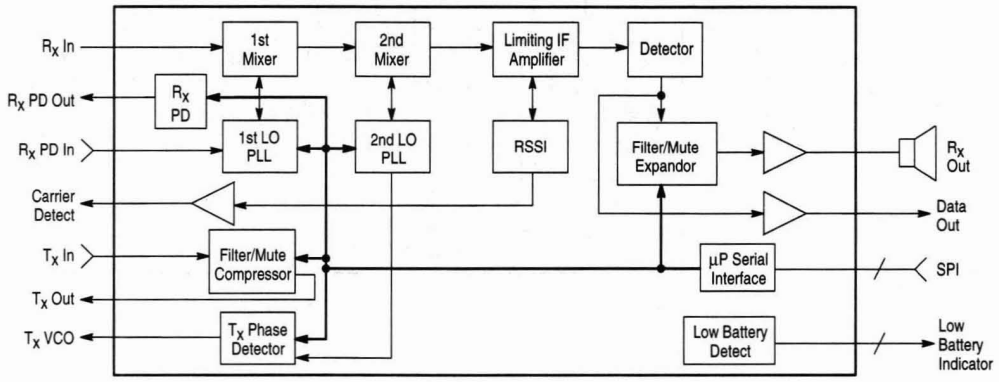



**FB SUFFIX**
PLASTIC QFP PACKAGE
CASE 848B

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC13111FB | $T_A$ = – 40° to +85°C | QFP–52 |

**Simplified Application**




This device contains 8,262 active transistors.

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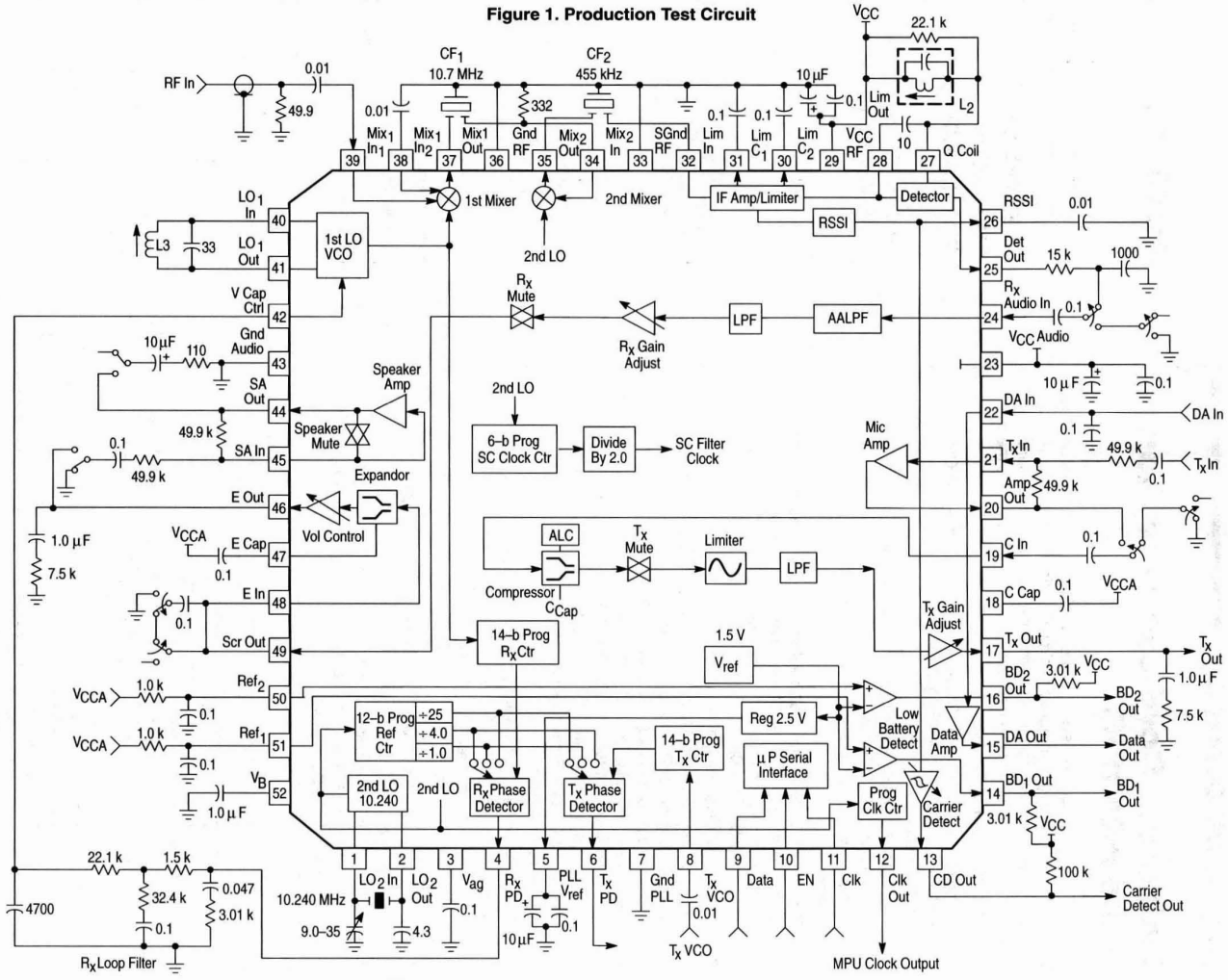
**Figure 1. Production Test Circuit**




**NOTE:** This schematic is only a representation of the actual production test circuit.

## MAXIMUM RATINGS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | −0.5 to +6.0 | Vdc |
| Junction Temperature | $T_J$ | −65 to +150 | °C |

**NOTES:** 1. Devices should not be operated at these limits. The "Recommended Operating Conditions" provide for actual device operation.
2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 2.7 | 3.6 | 5.5 | Vdc |
| Operating Ambient Temperature | $T_A$ | −40 | – | 85 | °C |
| Input Voltage Low (Data, Clk, EN) | $V_{IL}$ | – | – | 0.3 | V |
| Input Voltage High (Data, Clk, EN) | $V_{IH}$ | 2.5 | – | – | V |
| Output Current ($R_X$ PD, $T_X$ PD)<br>High<br>Low | <br>$I_{OH}$<br>$I_{OL}$ | <br>–<br>0.7 | <br>–<br>– | <br>−0.7<br>– | mA |

**NOTE:** All limits are not necessarily functional concurrently.

## DC ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 3.6 V, $T_A$ = 25°C, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Static Current | | | | | |
| Active Mode (2.7 V) | ACT $I_{CC}$ | – | 8.1 | – | mA |
| Active Mode | ACT $I_{CC}$ | – | 8.6 | 12 | mA |
| Receive Mode | $R_X$ $I_{CC}$ | – | 4.3 | 5.3 | mA |
| Standby Mode | STD $I_{CC}$ | – | 270 | 500 | µA |
| Inactive Mode | INACT $I_{CC}$ | – | 35 | 80 | µA |

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **PLL VOLTAGE REGULATOR** | | | | | | | | |
| Regulated Output Level | $I_L$ = 0 mA | – | PLL $V_{ref}$ | $V_O$ | 2.4 | 2.5 | 2.6 | V |
| Line Regulation | $I_L$ = 0 mA, $V_{CC}$ = 3.6 to 5.5 V | $V_{CC}$ Audio | PLL $V_{ref}$ | $V_{Reg}$ Line | – | −0.6 | 20 | mV |
| Load Regulation | $V_{CC}$ = 3.6 V, $I_L$ = 1.0 mA | $V_{CC}$ Audio | PLL $V_{ref}$ | $V_{Reg}$ Load | – | −1.1 | 20 | mV |
| **PLL LOOP CHARACTERISTICS** | | | | | | | | |
| 2nd LO Frequency (No Crystal) | – | $LO_2$ In | – | $f_{2ext}$ | – | 12 | – | MHz |
| 2nd LO Frequency (With Crystal) | – | – | $LO_2$ In $LO_2$ Out | $f_{2ext}$ | – | 12 | – | MHz |
| $T_X$ VCO (Input Frequency) | $V_{in}$ = 200 mVpp | – | $T_X$ VCO | $f_{txmax}$ | – | 80 | – | MHz |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **PLL PHASE DETECTOR** | | | | | | | | |
| Output Voltage Low | $I_{IL}$ = 0.7 mA | – | $R_X$ PD<br>$T_X$ PD | $V_{OL}$ | – | – | (PLL $V_{ref}$) *.2 | V |
| Output Voltage High | $I_{IH}$ = –0.7 mA | – | $R_X$ PD<br>$T_X$ PD | $V_{OL}$ | (PLL $V_{ref}$) *.8 | – | – | V |
| 3–State Leakage Current | V = 1.2 V | – | $R_X$ PD<br>$T_X$ PD | $I_{OZ}$ | –50 | – | 50 | nA |
| Output Capacitance | – | – | $R_X$ PD<br>$T_X$ PD | $C_{out}$ | – | 8.0 | – | pF |
| Output Rise and Fall Time | $C_{Load}$ = 50 pF | – | $R_X$ PD<br>$T_X$ PD<br>Clk Out | $t_r$, $t_f$ | – | 250 | – | ns |
| **MICROPROCESSOR SERIAL INTERFACE** | | | | | | | | |
| Input Current Low | $V_{in}$ = 0.3 V<br>Standby Mode | – | Data,<br>Clk, EN | $I_{IL}$ | –5.0 | 0.3 | – | µA |
| Input Current High | $V_{in}$ = 3.3 V<br>Standby Mode | – | Data,<br>Clk, EN | $I_{IH}$ | – | 1.5 | 5.0 | µA |
| Hysteresis Voltage | – | – | Data,<br>Clk, EN | $V_{hys}$ | – | 1.0 | – | V |
| Maximum Clock Frequency | – | Data,<br>EN, Clk | – | – | – | 2.0 | – | MHz |
| Input Capacitance | – | Data,<br>Clk, EN | – | $C_{in}$ | – | 8.0 | – | pF |
| EN to Clk Setup Time | – | – | EN, Clk | $t_{suEC}$ | – | 200 | – | ns |
| Data to Clk Setup Time | – | – | Data, Clk | $t_{suDC}$ | – | 100 | – | ns |
| Hold Time | – | – | Data, Clk | $t_h$ | – | 90 | – | ns |
| Recovery Time | – | – | EN, Clk | $t_{rec}$ | – | 90 | – | ns |
| Input Pulse Width | – | – | EN, Clk | $t_w$ | – | 100 | – | ns |
| Input Rise and Fall Time | – | – | Data,<br>Clk, EN | $t_r$, $t_f$ | – | 9.0 | – | µs |
| MPU Interface Power–Up Delay | 90% of PLL $V_{ref}$ to Data, Clk, EN | – | – | $t_{puMPU}$ | – | 100 | – | µs |
| **FM RECEIVER** ($f_{RF}$ = 46.77 MHz [USA Ch 21], $f_{dev}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz) | | | | | | | | |
| Sensitivity (Input for 12 dB SINAD) | 50 Ω Termination | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | 2.8<br>–98 | –<br>– | µVrms<br>dBm |
| | Single–Ended, Matched Input Generator Referred | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | 1.0<br>–107 | –<br>– | µVrms<br>dBm |
| | Differential, Matched Input Generator Referred | $Mix_1$ $In_{1/2}$ | Det Out | $V_{SIN}$ | –<br>– | .56<br>–112 | –<br>– | µVrms<br>dBm |
| 1st Mixer Voltage Conversion Gain | $V_{in}$ = 1.0 mVrms, with $CF_1$ Filter as Load | $Mix_1$ $In_{1/2}$ | $Mix_1$ Out | $MX_{gain1}$ | – | 12 | – | dB |
| 2nd Mixer Voltage Conversion Gain | $V_{in}$ = 3.0 mVrms, with $CF_2$ Filter as Load | $Mix_2$ In | $Mix_2$ Out | $MX_{gain2}$ | – | 20 | – | dB |
| 1st and 2nd Mixer Voltage Gain Total | $V_{in}$ = 1.0 mVrms, with $CF_1$ and $CF_2$ Load | $Mix_1$ $In_{1/2}$ | $Mix_2$ Out | $MX_{gainT}$ | 24 | 28 | – | dB |
| 1st Mixer Input Impedance | Single–Ended Input | – | $Mix_1$ $In_{1/2}$ | $R_{P1}$<br>$C_{P1}$ | –<br>– | 875<br>2.7 | –<br>– | Ω<br>pF |
| 2nd Mixer Input Impedance | $f_{in}$ = 10.7 MHz | – | $Mix_2$ In | $Z_{in2}$ | – | 3.0 | – | kΩ |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_x$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **FM RECEIVER** ($f_{RF}$ = 46.77 MHz [USA Ch 21], $f_{dev}$ = ±3.0 kHz, $f_{mod}$ = 1.0 kHz) | | | | | | | | |
| 1st Mixer Output Impedance | – | – | $Mix_1$ Out | $Z_{out1}$ | – | 330 | – | Ω |
| 2nd Mixer Output Impedance | – | – | $Mix_2$ Out | $Z_{out2}$ | – | 1.5 | – | kΩ |
| IF –3.0 dB Limiting Sensitivity | $f_{in}$ = 455 kHz | Lim In | Det Out | IF Sens | – | 71 | 100 | μVrms |
| Total Harmonic Distortion | With $R_C$ = 15 k/1.0 nF Filter at Det Out | $Mix_1$ $In_1$ | Det Out | THD | – | 1.3 | 2.0 | % |
| Recovered Audio | $V_{in}$ = 3.16 mVrms with $R_C$ = 15 k/1000 pF Filter at Det Out | $Mix_1$ $In_1$ | Det Out | AFO | 80 | 105 | 150 | mVrms |
| Demodulator Bandwidth | – | Lim In | Det Out | BW | – | 20 | – | kHz |
| Signal to Noise Ratio | $V_{in}$ = 3.16 mVrms, $R_C$ = 15 k/1000 pF | $Mix_1$ $In_1$ | Det Out | SN | – | 49 | – | dB |
| AM Rejection Ratio | $V_{in}$ = 3.16 mVrms, 30% AM, @ 1.0 kHz, $R_C$ = 15 k/1000 pF | $Mix_1$ $In_1$ | Det Out | AMR | 30 | 47 | – | dB |
| 1st Mixer, 1.0 dB Voltage Compression (Input Pin Referred) | – | $Mix_1$ $In_{1/2}$ | $Mix_1$ Out | $V_O$ 1.0 dB $Mix_1$ | – | 15 | – | mVrms |
| 2nd Mixer, 1.0 dB Voltage Compression (Input Pin Referred) | 50 Ω Input | $Mix_2$ In | $Mix_2$ Out | $V_O$ 1.0 dB $Mix_2$ | – | 14 | – | mVrms |
| 1st Mixer 3rd Order Intercept (Input Pin Referred) | $V_{in}$ = 3.98 mVrms | $Mix_1$ $In_1$ | $Mix_1$ Out | $TOI_{mix1}$ | – | 56 | – | mVrms |
| 2nd Mixer 3rd Order Intercept (Input Pin Referred) | $V_{in}$ = 3.98 mVrms, 50 Ω Input | $Mix_2$ In | $Mix_2$ Out | $TOI_{mix2}$ | – | 53 | – | mVrms |
| Detector Output Impedance | – | – | Det Out | $Z_O$ | – | 870 | – | Ω |
| **RSSI/CARRIER DETECT** ($R_L$ = 100 kΩ) | | | | | | | | |
| RSSI Output Current Dynamic Range | – | $Mix_1$ In | RSSI | RSSI | – | 80 | – | dB |
| Carrier Sense Threshold | CD Threshold Adjust = (10100) | $Mix_1$ In | CD Out | $V_T$ | – | 33 | – | μVrms |
| Hysteresis | – | Mix1 In | CD Out | Hys | – | 3.6 | 7.0 | dB |
| Output High Voltage | $V_{in}$ = 0 Vrms, CD = (10100) | $Mix_1$ In | CD Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in}$ = –80 dBV, CD = (10100) | $Mix_1$ In | CD Out | $V_{OL}$ | – | 0.02 | 0.4 | V |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_X$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **RSSI/CARRIER DETECT** ($R_L$ = 100 kΩ) | | | | | | | | |
| Carrier Sense Threshold Adjustment Range | Programmable through MPU Interface | – | – | $V_{T\ low}$ range | –20 | – | – | dB |
| | | – | – | $V_{T\ hi}$ range | – | – | 11 | |
| Carrier Sense Threshold – Number of Steps | Programmable through MPU Interface | – | – | $V_{Tn}$ | – | 32 | – | – |
| **DATA AMP COMPARATOR** | | | | | | | | |
| Hysteresis | – | DA In | DA Out | Hys | 30 | 40 | 50 | mV |
| Threshold Voltage | – | DA In | DA Out | $V_T$ | 2.7 | $V_{CC}$ – 0.7 | – | V |
| Input Impedance | – | – | DA In | $Z_I$ | – | 11 | – | kΩ |
| Output Impedance | – | – | DA Out | $Z_O$ | – | 100 | – | kΩ |
| Output High Voltage | $V_{in}$ = $V_{CC}$ – 1.0 V, $I_{OH}$ = 0 mA | DA In | DA Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in}$ = $V_{CC}$ – 0.4 V, $I_{OL}$ = 0 mA | DA In | DA Out | $V_{OL}$ | – | 0.04 | 0.4 | V |
| **$R_X$ AUDIO PATH** ($f_{in}$ = 1.0 kHz) | | | | | | | | |
| Absolute Gain | $V_{in}$ = –20 dBV | E In | E Out | G | –3.0 | 0 | 3.0 | dB |
| Gain Tracking | $V_{in}$ = –30 dBV<br>$V_{in}$ = –40 dBV | E In | E Out | $G_t$ | –21<br>–42 | –20<br>–40 | –19<br>–38 | dB |
| Total Harmonic Distortion | $V_{in}$ = –20 dBV | E In | E Out | THD | – | 0.5 | 1.0 | % |
| Maximum Input Voltage | – | $R_X$ Audio In | – | – | – | –11.5 | – | dBV |
| Maximum Output Voltage | Increase input voltage until output voltage THD = 5.0%, then measure output voltage. $R_L$ = 7.5 k/1.0 µF | E In | E Out | $V_{Omax}$ | – | 0 | – | dBV |
| Input Impedance | – | $R_X$ Audio In<br>E In | – | $Z_{in}$ | –<br>– | 600<br>7.5 | –<br>– | kΩ |
| Attack Time | $E_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | E In | E Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $E_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | E In | E Out | $t_r$ | – | 13.5 | – | ms |
| Compressor to Expandor Crosstalk | $V_{in}$ = –10 dBV, $V_{(E\ In)}$ = AC Gnd | C In | E Out | $C_T$ | – | –90 | –70 | dB |
| $R_X$ Data Muting (Δ Gain) | $V_{in}$ = –20 dBV, $R_X$ Gain Adj = (01111) | $R_X$ Audio In | E Out | $M_e$ | – | –83 | –60 | dB |
| $R_X$ High Frequency Corner (Note 1) | $R_X$ Path, V $R_X$ Audio In = –20 dBV | $R_X$ Audio In | Scr Out | $R_X$ $f_{ch}$ | – | 3.879 | – | kHz |
| **SPEAKER AMP/SP MUTE** | | | | | | | | |
| Maximum Output Swing | $R_L$ = 130 Ω | SA In | SA Out | $V_{Omax}$ | 0.8 | 0.9 | – | Vpp |
| Speaker Amp Muting | $V_{in}$ = –20 dBV | SA In | SA Out | $M_{sp}$ | – | –90 | –60 | dB |
| **$T_X$ AUDIO PATH** ($f_{in}$ = 1.0 kHz, $T_X$ Gain Adj = (01111), $f_{in}$ = 1.0 kHz) | | | | | | | | |
| Absolute Gain | $V_{in}$ = –10 dBV, ALC, Lim Disabled | $T_X$ In | $T_X$ Out | G | –4.0 | 0 | 4.0 | dB |
| Gain Tracking | $V_{in}$ = –30 dBV<br>$V_{in}$ = –40 dBV | $T_X$ In | $T_X$ Out | $G_t$ | –11<br>–17 | –10<br>–20 | –9.0<br>–13 | dB |
| Total Harmonic Distortion | $V_{in}$ = –10 dBV | $T_X$ In | $T_X$ Out | THD | – | 0.6 | 1.1 | % |

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**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = 3.6 V, $V_B$ = 1.5 V, $T_A$ = 25°C, Active or $R_x$ Mode, unless otherwise specified; Test Circuit Figure 1.)

| Characteristic | Condition | Input Pin | Measure Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **$T_x$ AUDIO PATH** ($f_{in}$ = 1.0 kHz, $T_x$ Gain Adj = (01111), $f_{in}$ = 1.0 kHz) | | | | | | | | |
| Maximum Output Voltage | Increase input voltage until output voltage THD = 5.0%, then measure output voltage. $R_L$ = 7.5 k/1.0 µF | C In | $T_x$ Out | $V_{Omax}$ | – | –5.0 | – | dBV |
| Input Impedance | – | C In | $T_x$ Out | $Z_{in}$ | – | 10 | – | kΩ |
| Attack Time | $C_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | C In | $T_x$ Out | $t_a$ | – | 3.0 | – | ms |
| Release Time | $C_{cap}$ = 0.5 µF, $R_{filt}$ = 40 k (See Appendix B) | C In | $T_x$ Out | $t_r$ | – | 13.5 | – | ms |
| Expandor to Compressor Crosstalk | $V_{in}$ = –20 dBV, Speaker Amp No Load, $V_{(C\ In)}$ = AC Gnd | E In | $T_x$ Out | $C_T$ | – | –60 | –40 | dB |
| $T_x$ Muting | $V_{in}$ – 10 dBV | $T_x$ In | $T_x$ Out | $M_c$ | – | –90 | –60 | dB |
| ALC Output Level | $V_{in}$ = –10 dBV<br>$V_{in}$ = –2.5 dBV<br>Limiter and Mutes disabled | $T_x$ In | $T_x$ Out | $ALC_{out}$ | –15<br>–13 | –11<br>–10 | –8.0<br>–6.0 | dBV |
| Limiter Output Level | $V_{in}$ = –2.5 dBV, ALC disabled | $T_x$ In | $T_x$ Out | $V_{lim}$ | –10 | –7.0 | – | dBV |
| $T_x$ High Frequency Corner (Note 1) | $T_x$ Path, V $T_x$ In = –10 dBV, Mic Amp = Unity Gain | $T_x$ In | $T_x$ Out | $T_x f_{ch}$ | – | 3.7 | – | kHz |
| **MIC AMP** ($f_{in}$ = 1.0 kHz, External resistors set to gain of 1) | | | | | | | | |
| Open Loop Gain | – | $T_x$ In | Amp Out | AVOL | – | 100,000 | – | V/V |
| Gain Bandwidth | – | $T_x$ In | Amp Out | GBW | – | 100 | – | kHz |
| Maximum Output Swing | $R_L$ = 10 kΩ | $T_x$ In | Amp Out | $V_{Omax}$ | – | 2.8 | – | Vpp |
| **LOW BATTERY DETECT** | | | | | | | | |
| Average Threshold Voltage Before Electronic Adjustment | $V_{CC}$ = 3.6 V, $V_{ref}$_Adj = (0111). Take average of rising and falling threshold | $Ref_1$<br>$Ref_2$ | $BD_1$ Out<br>$BD_2$ Out | $VT_i$ | 1.36 | 1.5 | 1.64 | V |
| Average Threshold Voltage After Electronic Adjustment | $V_{CC}$ = 3.6 V, $V_{ref}$_Adj = (adjusted value). Take average of rising and falling threshold | $Ref_1$<br>$Ref_2$ | $BD_1$ Out<br>$BD_2$ Out | $VT_f$ | 1.475 | 1.5 | 1.525 | V |
| Hysteresis | – | $Ref_1$<br>$Ref_2$ | $BD_1$ Out<br>$BD_2$ Out | Hys | – | 4.0 | – | mV |
| Input Current | $V_{in}$ = 1.0 to 2.0 V | – | $Ref_1$<br>$Ref_2$ | $I_{in}$ | –50 | – | 50 | nA |
| Output High Voltage | $V_{in}$ = 2.0 V, $R_L$ = 3.9 kΩ to $V_{CC}$ | $Ref_1$<br>$Ref_2$ | $BD_1$ Out<br>$BD_2$ Out | $V_{OH}$ | $V_{CC}$ – 0.1 | 3.6 | – | V |
| Output Low Voltage | $V_{in}$ = 1.0 V, $R_L$ = 3.9 kΩ to $V_{CC}$ | $Ref_1$<br>$Ref_2$ | $BD_1$ Out<br>$BD_2$ Out | $V_{OL}$ | – | 0.1 | 0.4 | V |

**NOTE:** 1. The filter specification is based on a 10.24 MHz 2nd LO, and a switched–capacitor (SC) filter counter divider ratio of 31. If other 2nd LO frequencies and/or SC filter counter divider ratios are used, the filter corner frequency will be proportional to the resulting SC filter clock frequency.

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**PIN FUNCTION DESCRIPTION**

| Pin | Symbol | Type | Description |
|---|---|---|---|
| 1<br>2 | $LO_2$ In<br>LO2 Out | – | These pins form the PLL reference oscillator when connected to an external parallel–resonant crystal (10.24 MHz typical). The reference oscillator is also the second Local Oscillator ($LO_2$) for the RF receiver. "$LO_2$ In" may also serve as an input for an externally generated reference signal which is typically ac–coupled. |
| 3 | $V_{ag}$ | – | Internal reference voltage for switched capacitor filter section. |
| 4 | $R_X$ PD | Output | Three state voltage output of the $R_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $R_X$ PLL loop filter. It is important to minimize the line length and parasitic capacitance of this pin. |
| 5 | PLL $V_{ref}$ | – | PLL voltage regulator output pin. An internal voltage regulator provides a stable power supply voltage for the $R_X$ and $T_X$ PLL's and can also be used as a regulated supply voltage for other IC's. |
| 6 | $T_X$ PD | Output | Three state voltage output of the $T_X$ Phase Detector. This pin is either "high", "low", or "high impedance" depending on the phase difference of the phase detector input signals. During lock, very narrow pulses with a frequency equal to the reference frequency are present. This pin drives the external $T_X$ PLL loop filter. It is important to minimize the line length and parasitic capacitance of this pin. |
| 7 | Gnd PLL | Gnd | Ground pin for PLL section of IC. |
| 8 | $T_X$ VCO | Input | Transmit divide counter input which is driven by an ac–coupled external transmit loop VCO. The minimum signal level is 200 mVpp @ 60.0 MHz. This pin also functions as the test mode input for the counter tests. |
| 9<br>10<br>11 | Data<br>EN<br>Clk | Input | Microprocessor serial interface input pins for programming various counters and control functions. |
| 12 | Clk Out | Output | Microprocessor Clock Output which is derived from the 2nd LO crystal oscillator and a programmable divider. It can be used to drive a microprocessor and thereby reduce the number of crystals required in the system design. The driver has an internal resistor in series with the output which can be combined with an external capacitor to form a low pass filter to reduce radiated noise on the PCB. This output also functions as the output for the counter test modes. |
| 13 | CD Out | I/O | Dual function pin; 1) Carrier detect output (open collector with external 100 kΩ pull–up resistor. 2) Hardware interrupt input which can be used to "wake–up" from Inactive Mode. |
| 14 | $BD_1$ Out | Output | Low battery detect output #1 (open collector with external pull–up resistor). |
| 15 | DA Out | Output | Data amplifier output (open collector with internal 100 kΩ pull–up resistor). |
| 16 | $BD_2$ Out | Output | Low battery detect output #2 (open collector with external pull–up resistor). |
| 17 | $T_X$ Out | Output | $T_X$ path audio output. |
| 18 | C Cap | – | Compressor rectifier filter capacitor pin. Pull pin high through a capacitor. |
| 19 | C In | Input | Compressor input (ac–coupled). |
| 20 | Amp Out | Output | Microphone amplifier output. |
| 21 | $T_X$ In | Input | $T_X$ path input to microphone amplifier (Mic Amp) (ac–coupled). |
| 22 | DA In | Input | Data amplifier input (ac–coupled). |
| 23 | $V_{CC}$ Audio | Supply | $V_{CC}$ supply for audio section. |
| 24 | $R_X$ Audio In | Input | $R_X$ audio input (ac–coupled). |
| 25 | Det Out | Output | Audio output from FM detector. |
| 26 | RSSI | Output | Receive Signal Strength Indicator filter capacitor. |
| 27<br>28 | Q Coil<br>Lim Out | – | A quad coil or ceramic discriminator connected to these pins as part of the FM demodulator circuit. |
| 29 | $V_{CC}$ RF | Supply | $V_{CC}$ supply for RF receiver section. |
| 30<br>31 | Lim $C_2$<br>Lim $C_1$ | – | IF amplifier/limiter capacitor pins. |
| 32 | Lim In | Input | Signal input for IF amplifier/limiter. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Type | Description |
|---|---|---|---|
| 33 | SGND RF | Gnd | Ground pin for RF section of the IC. |
| 34 | $Mix_2$ In | Input | Second mixer input. |
| 35 | $Mix_2$ Out | Output | Second mixer output. |
| 36 | Gnd RF | Gnd | Ground pin for RF section of the IC. |
| 37 | $Mix_1$ Out | Output | First mixer output. |
| 38 | $Mix_1$ $In_2$ | Input | Negative phase first mixer input. |
| 39 | $Mix_1$ $In_1$ | Input | Positive phase first mixer input. |
| 40<br>41 | $LO_1$ In<br>$LO_1$ Out | – | Tank Elements for 1st LO Multivibrator Oscillator are connected to these pins. |
| 42 | $V_{cap}$ Ctrl | – | 1st LO Varactor Control Pin. |
| 43 | Gnd Audio | Gnd | Ground for audio section of the IC. |
| 44 | SA Out | Output | Speaker amplifier output. |
| 45 | SA In | Input | Speaker amplifier input (ac–coupled). |
| 46 | E Out | Output | Expandor output. |
| 47 | $E_{cap}$ | – | Expandor rectifier filter capacitor pin. Pull pin high through a capacitor. |
| 48 | E In | Input | Expandor Input. |
| 49 | Scr Out | Output | $R_X$ Audio Output. |
| 50 | $Ref_2$ | – | Reference voltage input for Low Battery Detect #2. |
| 51 | $Ref_1$ | – | Reference voltage input for Low Battery Detect #1. |
| 52 | $V_B$ | – | Internal half supply analog ground reference. |

### FM Receiver

The FM receiver can be used with either a quad coil or a ceramic resonator. The FM receiver and 1st LO have been designed to work for all country channels, including 25 channel U.S., without the need for any external switching circuitry (see Figure 32).

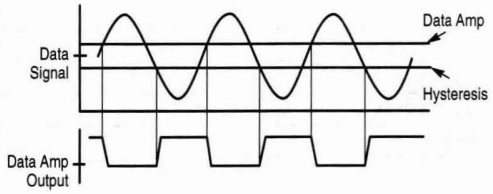
### RSSI/Carrier Detect

Connect 0.01 µF to Gnd from "RSSI" output pin to form the carrier detect filter. "CD Out" is an open collector output which requires an external 100 kΩ pull–up resistor to $V_{CC}$. The carrier detect threshold is programmable through the MPU interface.

### Data Amp Comparator

The data amp comparator is an inverting hysteresis comparator. Its open collector output has an internal 100 kΩ pull–up resistor. A band pass filter is connected between the "Det Out" pin and the "DA In" pin with component values as shown in Figure 1 (Test Circuit). The "DA In" input signal is ac–coupled.

**Figure 2. Data Amp Operation**

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### Expandor/ Compressor

In Appendix B, the EIA/CCITT recommendations for measurement of the attack and decay times are defined. The curves in Figures 3 and 4 show the typical expandor and compressor output versus input responses.

**Figure 3. Expandor Typical Response**

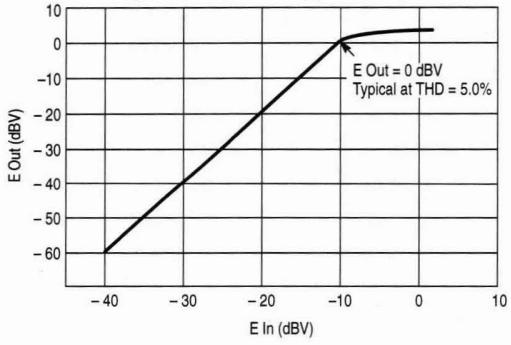
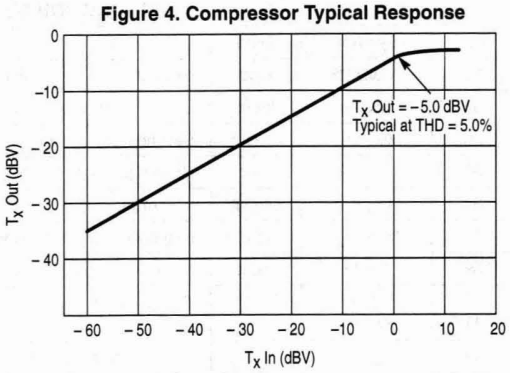



**Figure 4. Compressor Typical Response**




### $R_X$ Audio Path (LPF/$R_X$ Gain Adjust/ $R_X$ Mute/Expandor/Volume Control)

The $R_X$ Audio signal path goes from "$R_X$ Audio In" (Pin 24) to "E Out" (Pin 46). The "$R_X$ Audio In" input signal is ac coupled. AC couple between "Scr Out" and "E In" (see Figure 3).

### Speaker Amp/SP Mute

The Speaker Amp is an inverting rail–to–rail operational amplifier. The noninverting input is connected to the internal $V_B$ reference. External resistors and capacitors are used to set the gain and frequency response. The "SA In" Input is ac coupled.

### Mic Amp

The Mic Amp is an inverting rail–to–rail operational amplifier with noninverting input terminal connected to internal $V_B$ reference. External resistors and capacitors are set to the gain and frequency response. The "$T_X$ In" input is ac coupled.

### $T_X$ Audio Path (Compressor/ALC/$T_X$ Mute/ Limiter/LPF/$T_X$ Gain Adjust)

The $T_X$ Audio signal path goes from "$T_X$ In" (Pin 19) to "$T_X$ Out" (Pin 17). The "C In" input signal is ac coupled from "Amp Out". The ALC (Automatic Level Control) provides a "soft" limit to the output signal swing as the input voltage increases slowly (i.e., a sine wave is maintained). The Limiter circuit limits rapidly changing signal levels by clipping the signal peaks. The ALC and/or Limiter can be disabled through the MPU serial interface (see Figure 4).

### $T_X$ and $R_X$ Audio

Each audio path contains a low–pass switched capacitor filter (SCF). The control register must be set through the MPU interface (Figure 11) for proper operation ($T_X$ and $R_X$ bits must be set to "1"). The SCF corner frequencies are proportional to the SCF Clock. The SCF Clock Divider is programmable through the MPU interface as follows: (SCF) = F(2nd LO) / (SCF Divider Value * 2). The LPF corner frequencies can be

selected in from the table in Figures 28 and 29 relative to the 2nd LO operating frequency.

### PLL Voltage Regulator

The "PLL $V_{ref}$" pin is the internal supply voltage for the $R_X$ and $T_X$ PLL's. It is regulated to a nominal 2.5 V. The "$V_{CC}$ Audio" pin is the supply voltage for the internal voltage regulator. Two capacitors with 10 µF and 0.1 µF values must be connected to the "PLL $V_{ref}$" pin to filter and stabilize this regulated voltage. The "PLL $V_{ref}$" pin may be used to power other IC's as long as the total external load current does not exceed 1.0 mA. The tolerance of the regulated voltage is initially ±8.0%, but is improved to ±4.0% after the internal Bandgap voltage reference is adjusted electronically through the MPU serial interface. The voltage regulator is turned off in the Standby and Inactive modes to reduce current drain. In these modes, the "PLL $V_{ref}$" pin is internally connected to the "$V_{CC}$ Audio" pin (i.e., the power supply voltage is maintained but is now unregulated).

### Low Battery Detect

Two external precision resistor dividers are used to set independent thresholds for two battery detect hysteresis comparators. The voltages on "$Ref_1$" and "$Ref_2$" are compared to an internally generated 1.5 V reference voltage. The tolerance of the internal reference voltage is initially ±6.0%. The Low Battery Detect threshold tolerance can be improved by adjusting a trim–pot in the external resistor divider. Alternately, the tolerance of the internal reference voltage can be improved to ±1.5% through MPU serial interface programming. The internal reference can be measured directly at the "$V_B$" pin. During final test of the telephone, the $V_B$ internal reference voltage is measured. Then, the internal reference voltage value is adjusted electronically through the MPU serial interface to achieve the desired accuracy level. The voltage reference register value should be stored in ROM during final test so that it can be reloaded each time the MC13111 IC is powered up. Low Battery Detect outputs are open collector.

### Power Supply Voltage

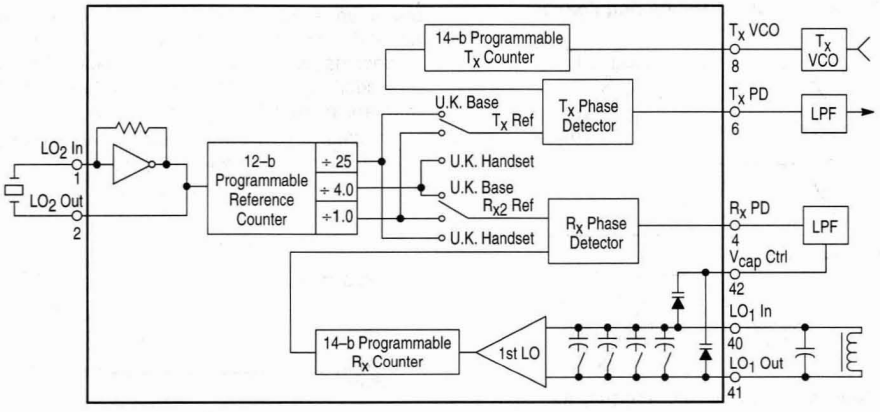
This circuit is used in a cordless telephone handset and base unit. The handset is battery powered and can operate on three NiCad cells or on 5.0 V supply.

### PLL Frequency Synthesizer General Description

Figure 5 shows a simplified block diagram of the programmable universal dual phase locked loop (PLL). This dual PLL is fully programmable through the MCU serial interface and supports most country channel frequencies including USA (25 ch), Spain, Australia, Korea, New Zealand, U. K., Netherlands, France, and China.

The 2nd local oscillator and reference divider provide the reference frequency for the receive ($R_X$) and transmit ($T_X$) PLL loops. The programmed divider value for the reference divider is selected based on the crystal frequency and the desired $R_X$ and $T_X$ reference frequency values. Additional divide by 25 and divide by 4 blocks are provided to allow for generation of the 1.0 kHz and 6.25 kHz reference frequencies required for the U. K. The 14–bit $T_X$ counter is programmed for the desired transmit channel frequency. The 14–bit $R_X$ counter is programmed for the desired first local oscillator frequency. All counters power up in the proper default state for USA channel #21 (channel #6 for FCC 10 channel band) and for a 10.24 MHz reference frequency crystal. Internal fixed capacitors can be connected to the tank circuit of the 1st LO through microprocessor control to extend the sensitivity of the 1st LO for U.S. 25 channel operation.

**Figure 5. Dual PLL Simplified Block Diagram**

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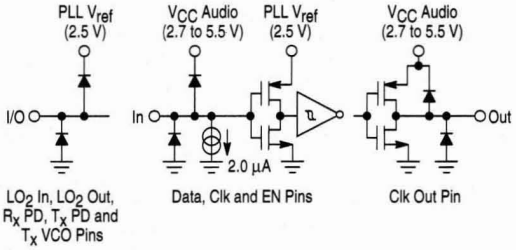
### PLL I/O Pin Specifications

The 2nd LO, $R_X$ and $T_X$ PLL's, and MPU serial interface are powered by the internal voltage regulator at the "PLL $V_{ref}$" pin. The "PLL $V_{ref}$" pin is the output of a voltage regulator which is powered from the "$V_{CC}$ Audio" power supply pin and is regulated by an internal bandgap voltage reference. Therefore, the maximum input and output levels for most PLL I/O pins ($LO_2$ In, $LO_2$ Out, $R_X$ PD, $T_X$ PD, $T_X$ VCO) is the regulated voltage at the "PLL $V_{ref}$" pin. The ESD protection diodes on these pins are also connected to "PLL $V_{ref}$". Internal level shift buffers are provided for the pins (Data, Clk, EN, Clk Out) which connect directly to the microprocessor. The maximum input and output levels for these pins is $V_{CC}$. Figure 6 shows a simplified schematic of the I/O pins.

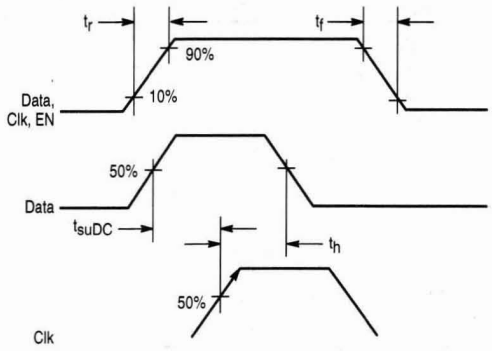
**Figure 6. PLL I/O Pin Simplified Schematics**




### Microprocessor Serial Interface

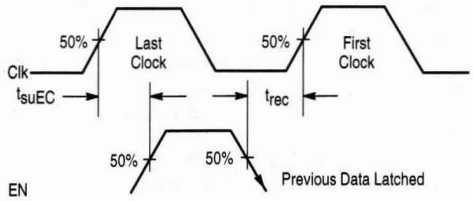
The "Data", "Clk", and "EN" pins provide an MPU serial interface for programming the reference counters, the transmit and receive channel divider counters, the switched capacitor filter clock counter, and various control functions. The "Data" and "Clk" pins are used to load data into the shift register. Figure 7 shows the timing required on the "Data" and "Clk" pins. Data is clocked into the shift register on positive clock transitions.

**Figure 7. Data and Clock Timing Requirement**



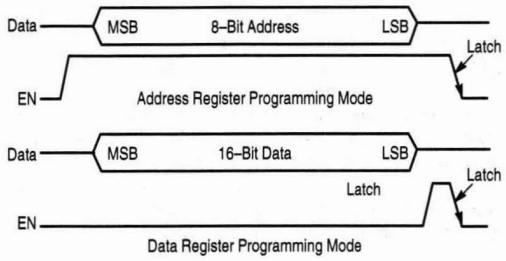

After data is loaded into the shift register, the data is latched into the appropriate latch register using the "EN" pin. This is done in two steps. First, an 8–bit address is loaded into the shift register and latched into the 8–bit address latch register. Then, up to 16–bits of data is loaded into the shift register and latched into the data latch register specified by the address that was previously loaded. Figure 5 shows the timing required on the EN pin. Latching occurs on the negative EN transition.

**Figure 8. Enable Timing Requirement**



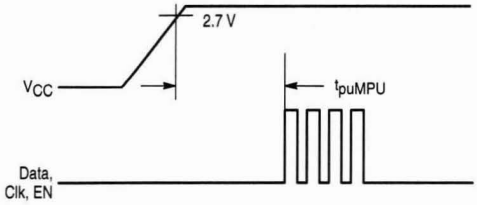

The state of the EN pin when clocking data into the shift register determines whether the data is latched into the address register or a data register. Figure 9 shows the address and data programming diagrams. In the data programming mode, there must not be any clock transitions when "EN" is high. The clock can be in a high state (default high) or a low state (default low) but must not have any transitions during the "EN" high state. The convention in these figures is that latch bits to the left are loaded into the shift register first.

**Figure 9. Microprocessor Interface Programming Mode Diagrams**




The MPU serial interface is fully operational within 100 µs after the power supply has reached its minimum level during power–up (see Figure 10). The MPU Interface shift registers and data latches are operational in all four power saving modes; Inactive, Standby, $R_X$, and Active Modes. Data can be loaded into the shift registers and latched into the latch registers in any of the operating modes.

**Figure 10. Microprocessor Serial Interface Power–Up Delay**




### Data Registers

Figure 11 shows shows the data latch registers and addresses which are used to select each of these registers. Latch bits to the left (MSB) are loaded into the shift register first. The LSB bit must always be the last bit loaded into the shift register. Bits preceeding the register must be "0's" as shown in Figure 11.

**Figure 11. Microprocessor Interface Data Latch Registers**

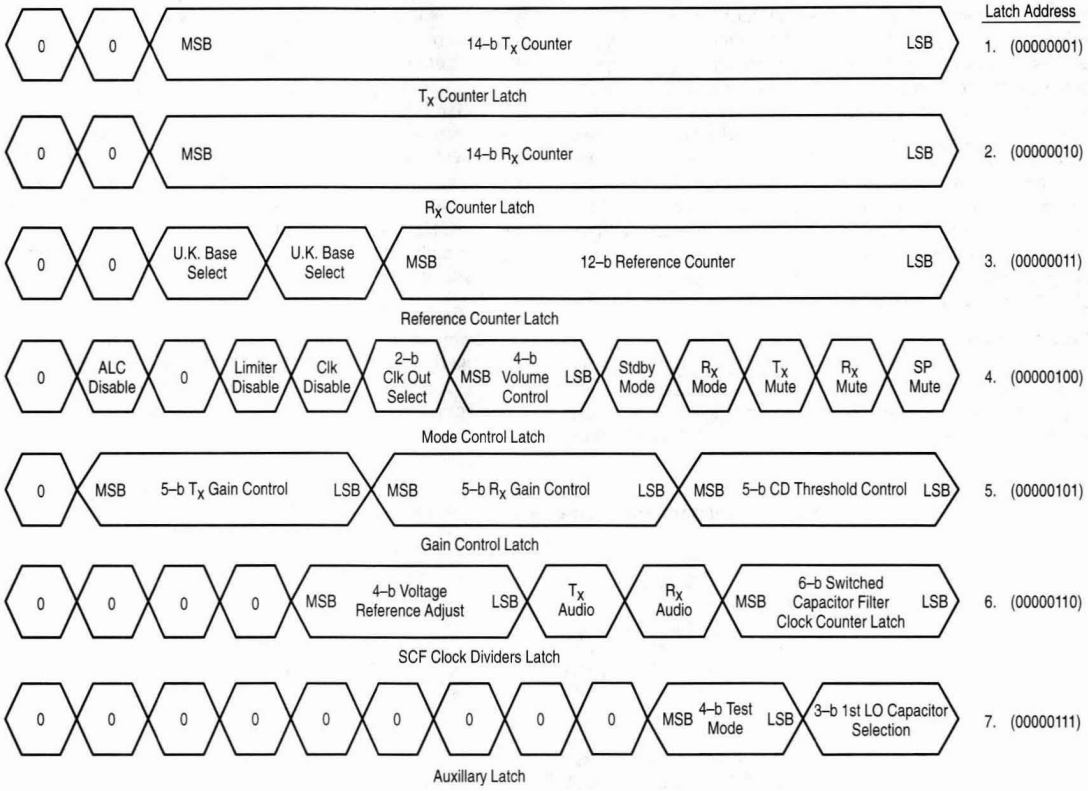

Latch Address
0 0 MSB 14–b $T_X$ Counter LSB
1. (00000001)
$T_X$ Counter Latch
0 0 MSB 14–b $R_X$ Counter LSB
2. (00000010)
$R_X$ Counter Latch
0 0 U.K. Base Select U.K. Base Select MSB 12–b Reference Counter LSB
3. (00000011)
Reference Counter Latch
0 ALC Disable 0 Limiter Disable Clk Disable 2–b Clk Out Select MSB 4–b Volume Control LSB Stdby Mode $R_X$ Mode $T_X$ Mute $R_X$ Mute SP Mute
4. (00000100)
Mode Control Latch
0 MSB 5–b $T_X$ Gain Control LSB MSB 5–b $R_X$ Gain Control LSB MSB 5–b CD Threshold Control LSB
5. (00000101)
Gain Control Latch
0 0 0 0 MSB 4–b Voltage Reference Adjust LSB $T_X$ Audio $R_X$ Audio MSB 6–b Switched Capacitor Filter Clock Counter Latch LSB
6. (00000110)
SCF Clock Dividers Latch
0 0 0 0 0 0 0 0 0 MSB 4–b Test Mode LSB 3–b 1st LO Capacitor Selection
7. (00000111)
Auxillary Latch

**Figure 12. Reference Frequency and Reference Divider Values**

| Crystal Frequency | Reference Divider Value | U.K. Base/ Handset Divider | Reference Frequency | SC Filter Clock Divider | SC Filter Clock Frequency |
|---|---|---|---|---|---|
| 10.24 MHz | 2048 | 1.0 | 5.0 kHz | 31 | 165.16 kHz |
| 10.24 MHz | 1024 | 4.0 | 2.5 kHz | 31 | 165.16 kHz |
| 11.15 MHz | 2230 | 1.0 | 5.0 kHz | 34 | 163.97 kHz |
| 12.00 MHz | 2400 | 1.0 | 5.0 kHz | 36 | 166.67 kHz |
| 11.15 MHz | 1784 | 1.0 | 6.25 kHz | 34 | 163.97 kHz |
| 11.15 MHz | 446 | 4.0 | 6.25 kHz | 34 | 163.97 kHz |
| 11.15 MHz | 446 | 25 | 1.0 kHz | 34 | 163.97 kHz |

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### Reference Frequency Selection

The "$LO_2$ In" and "$LO_2$ Out" pins form a reference oscillator when connected to an external parallel–resonant crystal. The reference oscillator is also the second local oscillator for the RF Receiver. Figure 12 shows the relationship between different crystal frequencies and reference frequencies for cordless phone applications in various countries. "$LO_2$ In" may also serve as an input for an externally generated reference signal which is ac–coupled. The switched capacitor filter 6–bit programmable counter must be programmed for the crystal frequency that is selected since this clock is derived from the crystal frequency and must be held constant regardless of the crystal that is selected. The actual switched capacitor clock divider ratio is twice the programmed divider ratio since there is a fixed divide by 2.0 after the programmable counter.

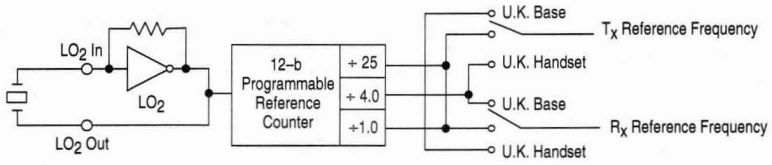
### Reference Counter

Figure 13 shows how the reference frequencies for the $R_X$ and $T_X$ loops are generated. All countries except the U.K. require that the $T_X$ and $R_X$ reference frequencies be identical. In this case, set "U.K. Base Select" and "U.K. Handset Select" bits to "0". Then the fixed divider is set to "1" and the $T_X$ and $R_X$ reference frequencies will be equal to the crystal oscillator frequency divided by the programmable reference counter value. The U.K. is a special case which requires a different reference frequency value for $T_X$ and $R_X$. For U.K. base operation, set "U.K. Base Select" to "1". For U.K. handset operation, set "U.K. Handset Select" to "1".The Netherlands is also a special case since a 2.5 kHz reference frequency is used for both the $T_X$ and $R_X$ reference and the total divider value required is 4096 which is larger than the maximum divide value available from the 12–bit reference divider (4095). In this case, set "U.K. Base Select" to "1" and set "U.K. Handset Select" to "1". This will give a fixed divide by 4 for both the $T_X$ and $R_X$ reference. Then set the reference divider to 1024 to get a total divider of 4096.

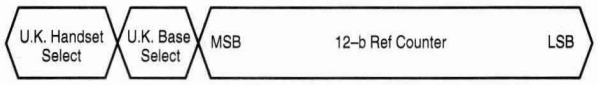
### Mode Control Register

Power saving modes, mutes, disables, volume control, and microprocessor clock output frequency are all set by the Mode Control Register. Operation of the Mode Control Register is explained in Figures 14 through 21.

**Figure 13. Reference Counter Register Programming Mode**




| U.K. Handset Select | U.K. Base Select | $T_X$ Divider Value | $R_X$ Divider Value | Application |
|---|---|---|---|---|
| 0 | 0 | 1.0 | 1.0 | All but U.K. and Netherlands |
| 0 | 1 | 25 | 4.0 | U.K. Base Set |
| 1 | 0 | 4.0 | 25 | U.K. Hand Set |
| 1 | 1 | 4.0 | 4.0 | Netherlands Base and Hand Set |




14–Bit Reference Counter Latch

**Figure 14. Mode Control Register Bits**

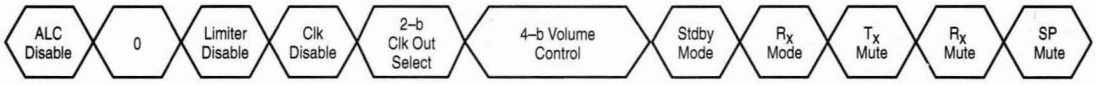


**Figure 15. Mute and Disable Control Bit Descriptions**

| | | |
|---|---|---|
| ALC Disable | 1<br>0 | Automatic Level Control Disabled<br>Normal Operation |
| Limiter Disable | 1<br>0 | Limiter Disabled<br>Normal Operation |
| Clock Disable | 1<br>0 | MPU Clock Output Disabled<br>Normal Operation |
| $T_X$ Mute | 1<br>0 | Transmit Channel Muted<br>Normal Operation |
| $R_X$ Mute | 1<br>0 | Receive Channel Muted<br>Normal Operation |
| SP Mute | 1<br>0 | Speaker Amp Muted<br>Normal Operation |

### Power Saving Operating Modes

When the MC13111 is used in a handset, it is important to conserve power in order to prolong battery life. There are five modes of operation; Active, $R_X$, Standby, Interrupt, and Inactive. In Active mode, all circuit blocks are powered. In $R_X$ mode, all circuitry is powered down except for those circuit sections needed to receive a transmission from the base. In the Standby and Interrupt Modes, all circuitry is powered down except for the circuitry needed to provide the clock output for the microprocessor. In Inactive Mode, all circuitry is powered down except the MPU interface. Latch memory is maintained in all modes. Figure 16 shows the control register bit values for selection of each power saving mode and Figure 17 shows the circuit blocks which are powered in each of these operating modes.

**Figure 16. Power Saving Mode Selection**

| Stdby Mode Bit | $R_X$ Mode Bit | "CD Out/ Hardware Interrupt" Pin | Mode |
|---|---|---|---|
| 0 | 0 | X | Active |
| 0 | 1 | X | $R_X$ |
| 1 | 0 | X | Standby |
| 1 | 1 | 1 or High Impedance | Inactive |
| 1 | 1 | 0 | Interrupt |

**Figure 17. Power Saving Modes**

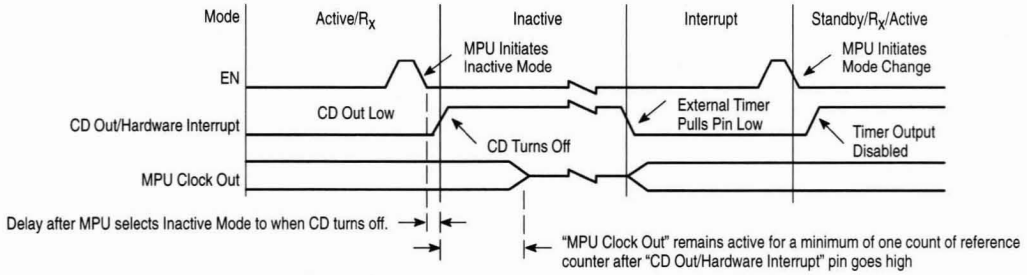
| Circuit Blocks | Active | $R_X$ | Standby | Inactive |
|---|---|---|---|---|
| "PLL $V_{ref}$" Regulated Voltage | X | X | X[1] | X[1] |
| MPU Interface | X | X | X | X |
| 2nd LO Oscillator | X | X | X | |
| MPU Clock Output | X | X | X | |
| RF Receiver and 1st LO VCO | X | X | | |
| $R_X$ PLL | X | X | | |
| Carrier Detect | X | X | | |
| Data Amp | X | X | | |
| Low Battery Detect | X | X | | |
| $T_X$ PLL | X | | | |
| $R_X$ and $T_X$ Audio Paths | X | | | |

**NOTE:** In Standby and Inactive Modes, "PLL $V_{ref}$" remains powered but is not regulated. It will fluctuate with $V_{CC}$.

### Inactive Mode Operation and Hardware Interrupt

In some handset applications it may be desirable to power down all circuitry including the microprocessor (MPU). First put the combo IC into the Inactive mode, which turns off the MPU Clock Output (see Figure 18), and then disable the microprocessor. In order to give the MPU adequate time to power down, the MPU Clock output remains active for a minimum of one reference counter cycle (about 200 µs) after the command is given to switch into the "Inactive" mode. An external timing circuit should be used to initiate the turn–on sequence. The "CD Out" pin has a dual function. In the Active and $R_X$ modes it performs the carrier detect function. In the Standby and Inactive modes the carrier detect circuit is disabled and the "CD Out" pin is in a "High" state due to the external pull–up resistor. In the Inactive mode, the "CD Out" pin is the input for the hardware interrupt function. When the "CD Out" pin is pulled "low" by the external timing circuit, the combo IC switches from the Inactive to the Interrupt mode thereby turning on the MPU Clock Output. The MPU can then resume control of the combo IC. The "CD Out" pin must remain low until the MPU changes the operating mode from Interrupt to Standby, Active or $R_X$ modes.

**Figure 18. Hardware Interrupt Operation**


Mode
Active/RX
Inactive
Interrupt
Standby/RX/Active
MPU Initiates Inactive Mode
MPU Initiates Mode Change
EN
CD Out Low
External Timer Pulls Pin Low
CD Out/Hardware Interrupt
CD Turns Off
Timer Output Disabled
MPU Clock Out
Delay after MPU selects Inactive Mode to when CD turns off.
"MPU Clock Out" remains active for a minimum of one count of reference counter after "CD Out/Hardware Interrupt" pin goes high

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### MPU "Clk Out" Divider Programming

This pin is a clock output which is derived from the crystal oscillator (2nd local oscillator). It can be used to drive a microprocessor and thereby reduce the number of crystals required. Figure 19 shows the relationship between the crystal frequency and the clock output for different divider values. Figure 20 shows the "Clk Out" register bit values.

**Figure 19. Clock Output Values**

| Crystal Frequency | Clock Output Divider | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| 10.24 MHz | 5.120 MHz | 3.413 MHz | 2.560 MHz | 2.048 MHz |
| 11.15 MHz | 5.575 MHz | 3.717 MHz | 2.788 MHz | 2.230 MHz |
| 12.00 MHz | 6.000 MHz | 4.000 MHz | 3.000 MHz | 2.400 MHz |

### MPU "Clk Out" Radiated Noise on Circuit Board

The clock line running between the MC13111 and the microprocessor has the potential to radiate noise which can cause problems in the system especially if the clock is a square wave digital signal with large high frequency harmonics. In order to minimize radiated noise, a 1.0 kΩ resistor is included on–chip in series with the "Clk Out" output driver. A small capacitor can be connected to the "Clk Out" line on the PCB to form a single pole low pass filter. This filter will significantly reduce noise radiated from the "Clk Out" line.

### Volume Control Programming

The volume control adjustable gain block can be programmed in 2.0 dB gain steps from –14 dB to +16 dB. The power–up default value is 0 dB. (See Figure 21.)

**Figure 20. Clock Output Divider**

| Clk Out Bit #1 | Clk Out Bit #0 | Clk Out Divider Value |
|---|---|---|
| 0 | 0 | 2 |
| 0 | 1 | 3 |
| 1 | 0 | 4 |
| 1 | 1 | 5 |

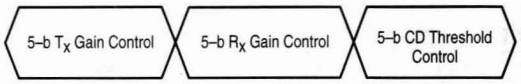
**Figure 21. Volume Control**

| Volume Control Bit #3 | Volume Control Bit #2 | Volume Control Bit #1 | Volume Control Bit #0 | Volume Control # | Gain/Attenuation Amount |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | –14 dB |
| 0 | 0 | 0 | 1 | 1 | –12 dB |
| 0 | 0 | 1 | 0 | 2 | –10 dB |
| 0 | 0 | 1 | 1 | 3 | –8.0 dB |
| 0 | 1 | 0 | 0 | 4 | –6.0 dB |
| 0 | 1 | 0 | 1 | 5 | –4.0 dB |
| 0 | 1 | 1 | 0 | 6 | –2.0 dB |
| 0 | 1 | 1 | 1 | 7 | 0 dB |
| 1 | 0 | 0 | 0 | 8 | 2.0 dB |
| 1 | 0 | 0 | 1 | 9 | 4.0 dB |
| 1 | 0 | 1 | 0 | 10 | 6.0 dB |
| 1 | 0 | 1 | 1 | 11 | 8.0 dB |
| 1 | 1 | 0 | 0 | 12 | 10 dB |
| 1 | 1 | 0 | 1 | 13 | 12 dB |
| 1 | 1 | 1 | 0 | 14 | 14 dB |
| 1 | 1 | 1 | 1 | 15 | 16 dB |

### Gain Control Register

The gain control register contains bits which control the $T_X$ Voltage Gain, $R_X$ Voltage Gain, and Carrier Detect threshold. Operation of these latch bits are explained in Figures 22, 23 and 24.

**Figure 22. Gain Control Latch Bits**




### $T_X$ and $R_X$ Gain Programming

The $T_X$ and $R_X$ audio signal paths each have a programmable gain block. If a $T_X$ or $R_X$ voltage gain other than the nominal power–up default is desired, it can be programmed through the MPU interface. Alternately, these programmable gain blocks can be used during final test of the telephone to electronically adjust for gain tolerances in the telephone system as shown in Figure 23. In this case, the $T_X$ and $R_X$ gain register values should be stored in ROM during final test so that they can be reloaded each time the combo IC is powered up.

**Figure 23. $T_X$ and $R_X$ Gain Control**

| Gain Control Bit #4 | Gain Control Bit #3 | Gain Control Bit #2 | Gain Control Bit #1 | Gain Control Bit #0 | Gain Control # | Gain/Attenuation Amount |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | –15 dB |
| 0 | 0 | 0 | 0 | 1 | 1 | –14 dB |
| 0 | 0 | 0 | 1 | 0 | 2 | –13 dB |
| 0 | 0 | 0 | 1 | 1 | 3 | –12 dB |
| 0 | 0 | 1 | 0 | 0 | 4 | –11 dB |
| 0 | 0 | 1 | 0 | 1 | 5 | –10 dB |
| 0 | 0 | 1 | 1 | 0 | 6 | –9.0 dB |
| 0 | 0 | 1 | 1 | 1 | 7 | –8.0 dB |
| 0 | 1 | 0 | 0 | 0 | 8 | –7.0 dB |
| 0 | 1 | 0 | 0 | 1 | 9 | –6.0 dB |
| 0 | 1 | 0 | 1 | 0 | 10 | –5.0 dB |
| 0 | 1 | 0 | 1 | 1 | 11 | –4.0 dB |
| 0 | 1 | 1 | 0 | 0 | 12 | –3.0 dB |
| 0 | 1 | 1 | 0 | 1 | 13 | –2.0 dB |
| 0 | 1 | 1 | 1 | 0 | 14 | –1.0 dB |
| 0 | 1 | 1 | 1 | 1 | 15 | 0 dB |
| 1 | 0 | 0 | 0 | 0 | 16 | 1.0 dB |
| 1 | 0 | 0 | 0 | 1 | 17 | 2.0 dB |
| 1 | 0 | 0 | 1 | 0 | 18 | 3.0 dB |
| 1 | 0 | 0 | 1 | 1 | 19 | 4.0 dB |
| 1 | 0 | 1 | 0 | 0 | 20 | 5.0 dB |
| 1 | 0 | 1 | 0 | 1 | 21 | 6.0 dB |
| 1 | 0 | 1 | 1 | 0 | 22 | 7.0 dB |
| 1 | 0 | 1 | 1 | 1 | 23 | 8.0 dB |
| 1 | 1 | 0 | 0 | 0 | 24 | 9.0 dB |
| 1 | 1 | 0 | 0 | 1 | 25 | 10 dB |
| 1 | 1 | 0 | 1 | 0 | 26 | 11 dB |
| 1 | 1 | 0 | 1 | 1 | 27 | 12 dB |
| 1 | 1 | 1 | 0 | 0 | 28 | 13 dB |
| 1 | 1 | 1 | 0 | 1 | 29 | 14 dB |
| 1 | 1 | 1 | 1 | 0 | 30 | 15 dB |
| 1 | 1 | 1 | 1 | 1 | 31 | 16 dB |

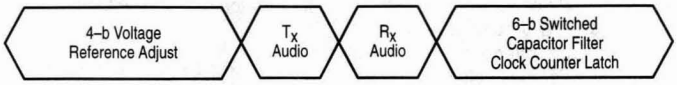
**Carrier Detect Threshold Programming**

The "CD Out" pin gives an indication to the microprocessor if a carrier signal is present on the selected channel. The nominal value and tolerance of the carrier detect threshold is given in the carrier detect specification section of this document. If a different carrier detect threshold value is desired, it can be programmed through the MPU interface as shown in Figure 24. Alternately, the carrier detect threshold can be electronically adjusted during final test of the telephone to reduce the tolerance of the carrier detect threshold. This is done by measuring the threshold and then by adjusting the threshold through the MPU interface. In this case, it is necessary to store the carrier detect register value in ROM so that the CD register can be reloaded each time the combo IC is powered up.

**Figure 24. Carrier Detect Threshold Control**

| CD Bit #4 | CD Bit #3 | CD Bit #2 | CD Bit #1 | CD Bit #0 | CD Control # | Carrier Detect Threshold |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | –20 dB |
| 0 | 0 | 0 | 0 | 1 | 1 | –19 dB |
| 0 | 0 | 0 | 1 | 0 | 2 | –18 dB |
| 0 | 0 | 0 | 1 | 1 | 3 | –17 dB |
| 0 | 0 | 1 | 0 | 0 | 4 | –16 dB |
| 0 | 0 | 1 | 0 | 1 | 5 | –15 dB |
| 0 | 0 | 1 | 1 | 0 | 6 | –14 dB |
| 0 | 0 | 1 | 1 | 1 | 7 | –13 dB |
| 0 | 1 | 0 | 0 | 0 | 8 | –12 dB |
| 0 | 1 | 0 | 0 | 1 | 9 | –11 dB |
| 0 | 1 | 0 | 1 | 0 | 10 | –10 dB |
| 0 | 1 | 0 | 1 | 1 | 11 | –9.0 dB |
| 0 | 1 | 1 | 0 | 0 | 12 | –8.0 dB |
| 0 | 1 | 1 | 0 | 1 | 13 | –7.0 dB |
| 0 | 1 | 1 | 1 | 0 | 14 | –6.0 dB |
| 0 | 1 | 1 | 1 | 1 | 15 | –5.0 dB |
| 1 | 0 | 0 | 0 | 0 | 16 | –4.0 dB |
| 1 | 0 | 0 | 0 | 1 | 17 | –3.0 dB |
| 1 | 0 | 0 | 1 | 0 | 18 | –2.0 dB |
| 1 | 0 | 0 | 1 | 1 | 19 | –1.0 dB |
| 1 | 0 | 1 | 0 | 0 | 20 | 0 dB |
| 1 | 0 | 1 | 0 | 1 | 21 | 1.0 dB |
| 1 | 0 | 1 | 1 | 0 | 22 | 2.0 dB |
| 1 | 0 | 1 | 1 | 1 | 23 | 3.0 dB |
| 1 | 1 | 0 | 0 | 0 | 24 | 4.0 dB |
| 1 | 1 | 0 | 0 | 1 | 25 | 5.0 dB |
| 1 | 1 | 0 | 1 | 0 | 26 | 6.0 dB |
| 1 | 1 | 0 | 1 | 1 | 27 | 7.0 dB |
| 1 | 1 | 1 | 0 | 0 | 28 | 8.0 dB |
| 1 | 1 | 1 | 0 | 1 | 29 | 9.0 dB |
| 1 | 1 | 1 | 1 | 0 | 30 | 10 dB |
| 1 | 1 | 1 | 1 | 1 | 31 | 11 dB |

**Figure 25. SCF Clock Divider Latch Bits**




### SCF Clock Divider

This register controls the divider value for the programmable switched capacitor filter clock divider and the voltage reference adjust. Operation is explained in Figures 25 through 30.

**Figure 26. Audio Mode Bit Description**

| | | |
|---|---|---|
| $T_X$ Mode | 1 | Normal $T_X$ Path Operation |
| | 0 | Undefined State |
| $R_X$ Mode | 1 | Normal $R_X$ Path Operation |
| | 0 | Undefined State |

**NOTES:** Power–up bit default mode is "0". Must change bit to "1" for proper operation.

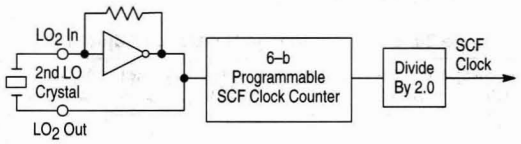
### Switched Capacitor Filter Clock Programming

A block diagram of the switched capacitor filter clock dividers is shown in Figure 27. There is a fixed divide by 2 after the programmable divider. The switched capacitor filter clock value is given by the following equation;

(SCF Clock) = F(2nd LO)/(SCF Divider Value * 2)

The SCF divider should be set to a value which gives a SCF Clock as close to 165.16 kHz as possible based on the 2nd LO frequency which is chosen (see Figure 12).

**Figure 27. SCF Clock Circuit**




### Corner Frequency Programming

Four different corner frequencies may be selected by programming the SCF Clock divider as shown in Figures 28 and 29. Note that all filter corner frequencies change proportionately with the SCF Clock Frequency. The power–up default SCF Clock divider is 31.

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**Figure 28. Corner Frequency Programming for a 10.240 MHz 2nd LO**

| SCF Clock Divider | Total Divide Value | SCF Clock Freq. (kHz) | $R_X$ Upper Corner Frequency (kHz) | $T_X$ Upper Corner Frequency (kHz) |
|---|---|---|---|---|
| 29 | 58 | 176.55 | 4.147 | 3.955 |
| 30 | 60 | 170.67 | 4.008 | 3.823 |
| 31 | 62 | 165.16 | 3.879 | 3.700 |
| 32 | 64 | 160.00 | 3.758 | 3.584 |

**NOTE:** All filter corner frequencies have a tolerance of ±3%.

**Figure 29. Corner Frequency Programming for a 11.15 MHz 2nd LO**

| SCF Clock Divider | Total Divide Value | SCF Clock Freq. (kHz) | $R_X$ Upper Corner Frequency (kHz) | $T_X$ Upper Corner Frequency (kHz) |
|---|---|---|---|---|
| 32 | 64 | 174.22 | 4.092 | 3.903 |
| 33 | 66 | 168.94 | 3.968 | 3.785 |
| 34 | 68 | 163.97 | 3.851 | 3.673 |
| 35 | 70 | 159.29 | 3.741 | 3.568 |

**NOTE:** All filter corner frequencies have a tolerance of ±3%.

### Voltage Reference Adjustment

The internal 1.5 V Bandgap voltage reference provides the voltage reference for the "BD1 Out" and "BD2 Out" low battery detect circuits, the "PLL $V_{ref}$" voltage regulator, the "$V_B$" reference, and all internal analog ground references. The initial tolerance of the Bandgap voltage reference is ±6%. The tolerance of the internal reference voltage can be improved to ±1.5% through MPU serial interface programming.

During final test of the telephone, the battery detect threshold is measured. Then, the internal reference voltage value is adjusted electronically through the MPU serial interface to achieve the desired accuracy level. The voltage reference register value should be stored in ROM during final test so that it can be reloaded each time the MC13111 is powered up (see Figure 30).

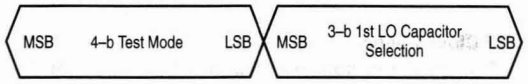
**Figure 30. Bandgap Voltage Reference Adjustment**

| $V_{ref}$Adj. Bit #3 | $V_{ref}$Adj. Bit #2 | $V_{ref}$Adj. Bit #1 | $V_{ref}$Adj. Bit #0 | $V_{ref}$Adj. # | $V_{ref}$ Adj. Amount |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | –9.0% |
| 0 | 0 | 0 | 1 | 1 | –7.8% |
| 0 | 0 | 1 | 0 | 2 | –6.6% |
| 0 | 0 | 1 | 1 | 3 | –5.4% |
| 0 | 1 | 0 | 0 | 4 | –4.2% |
| 0 | 1 | 0 | 1 | 5 | –3.0% |
| 0 | 1 | 1 | 0 | 6 | –1.8% |
| 0 | 1 | 1 | 1 | 7 | –0.6% |
| 1 | 0 | 0 | 0 | 8 | +0.6 % |
| 1 | 0 | 0 | 1 | 9 | +1.8 % |
| 1 | 0 | 1 | 0 | 10 | +3.0 % |
| 1 | 0 | 1 | 1 | 11 | +4.2 % |
| 1 | 1 | 0 | 0 | 12 | +5.4 % |
| 1 | 1 | 0 | 1 | 13 | +6.6 % |
| 1 | 1 | 1 | 0 | 14 | +7.8 % |
| 1 | 1 | 1 | 1 | 15 | +9.0 % |

### Auxiliary Register

The auxiliary register contains a 3–bit 1st LO Capacitor Selection latch and a 4–bit Test Mode latch. Operation of these latch bits are explained in Figures 31, 32 and 34.

**Figure 31. Auxiliary Register Latch Bits**




### First Local Oscillator Programmable Selection (U.S. Applications)

There is a very large frequency difference between the minimum and maximum channel frequencies in the 25 Channel U.S. Standard.The sensitivity of the 1st LO may not be large enough to accommodate this large frequency variation. Fixed capacitors can be connected across the 1st LO tank circuit to change the 1st LO sensitivity. Internal switches and capacitors are provided to enable microprocessor control over internal fixed capacitor values. Figures 32 and 33 show the schematic representation of the 1st LO and the tank circuit. Figure 34 shows the latch control bit values for microprocessor control.

**Figure 32. First Local Oscillator Schematic**

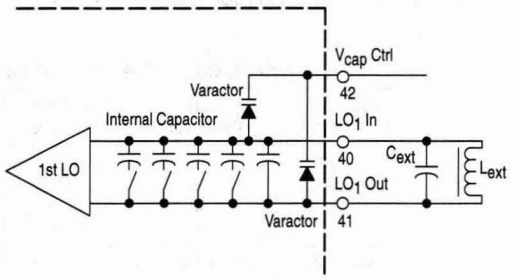


**Figure 33. First Local Oscillator Simplified Schematic**

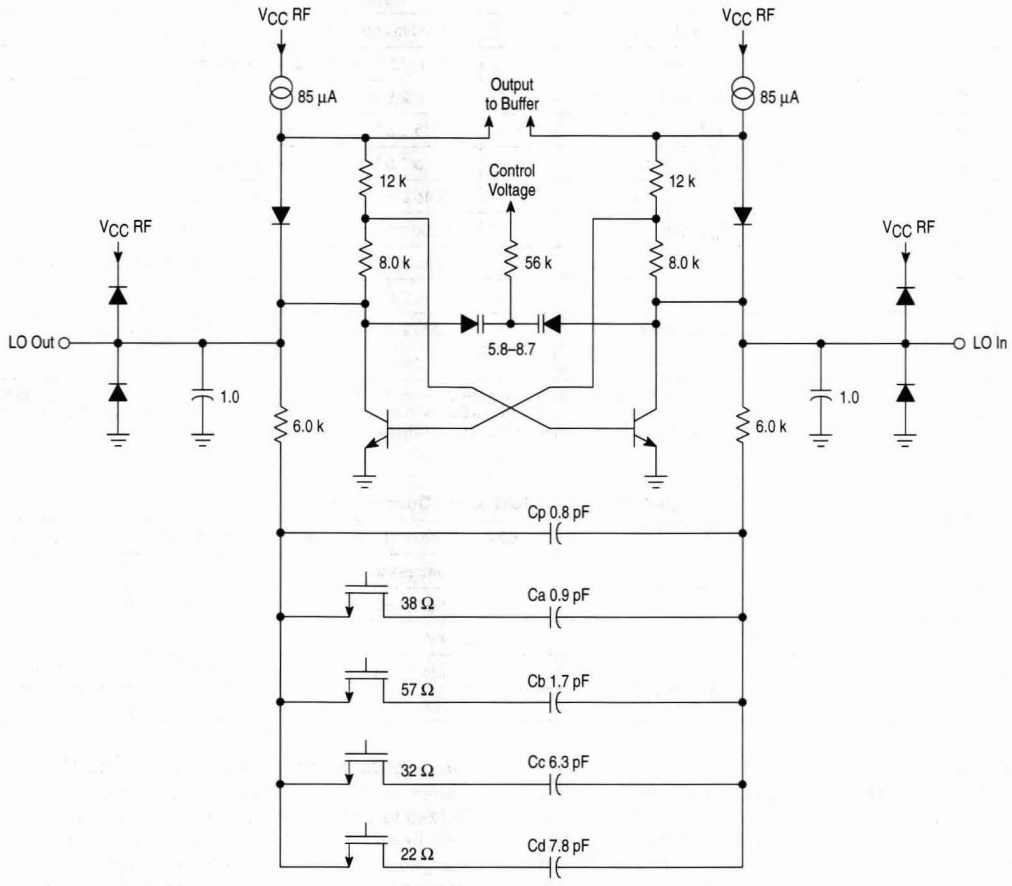



**Figure 34. First Local Oscillator Programmable Capacitor Selection for U.S. 25 Channels**

| 1st LO Cap. Bit 2 | 1st LO Cap. Bit 1 | 1st LO Cap Bit 0 | 1st LO Cap. Select | U.S. Base Channels | U.S. Handset Channels | Internal Capacitor Value | Varactor Value over 0.3 to 2.5 V | Equivalent Internal Parallel Resistance at 40 MHz (kΩ) | Equivalent Internal Parallel Resistance at 51 MHz (kΩ) | External Capacitor Value | External Inductor Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1–10 | – | 0.8 pF | 5.8–8.7 pF | >1000 | >1000 | 24 pF | 0.47 µH |
| 0 | 0 | 0 | 0 | – | 1–10 | 0.8 pF | 5.8–8.7 pF | >1000 | >1000 | 33 pF | 0.47 µH |
| 0 | 0 | 1 | 1 | 11–16 | – | 2.5 pF | 5.8–8.7 pF | 35 | 21 | 24 pF | 0.47 µH |
| 0 | 1 | 0 | 2 | 17–25 | – | 1.7 pF | 5.8–8.7 pF | 100 | 60 | 24 pF | 0.47 µH |
| 0 | 1 | 1 | 3 | – | 11–16 | 8.6 pF | 5.8–8.7 pF | 6.1 | 3.8 | 33 pF | 0.47 µH |
| 1 | 0 | 0 | 4 | – | 17–25 | 7.1 pF | 5.8–8.7 pF | 8.0 | 5.0 | 33 pF | 0.47 µH |

**Figure 35. Digital Test Mode Description**

| TM # | TM 3 | TM 2 | TM 1 | TM 0 | Counter Under Test or Test Mode Option | "$T_X$ $V_{CO}$" Input Signal | "Clk Out" Output Expected |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | Normal Operation | >200 mVpp | – |
| 1 | 0 | 0 | 0 | 1 | $R_X$ Counter, upper 6 | 0 to 2.5 V | Input Frequency/64 |
| 2 | 0 | 0 | 1 | 0 | $R_X$ Counter, lower 8 | 0 to 2.5 V | See Note Below |
| 3 | 0 | 0 | 1 | 1 | $R_X$ Prescaler | 0 to 2.5 V | Input Frequency/4 |
| 4 | 0 | 1 | 0 | 0 | $T_X$ Counter, upper 6 | 0 to 2.5 V | Input Frequency/64 |
| 5 | 0 | 1 | 0 | 1 | $T_X$ Counter, lower 8 | 0 to 2.5 V | See Note Below |
| 6 | 0 | 1 | 1 | 0 | $T_X$ Prescaler | >200 mVpp | Input Frequency/4 |
| 7 | 0 | 1 | 1 | 1 | Reference Counter | 0 to 2.5 V | Input Frequency/Reference Counter Value |
| 8 | 1 | 0 | 0 | 0 | Divide by 4, 25 | 0 to 2.5 V | Input Frequency/100 |
| 9 | 1 | 0 | 0 | 1 | SC Counter | 0 to 2.5 V | Input Frequency/SC Counter Value |
| 10 | 1 | 0 | 1 | 0 | Not Used | N/A | – |

**NOTE:** To determine the correct output, look at the lower 8–bits in the $R_X$ or $T_X$ register (Divisor (7;0). If the value of the divisor is > 16, then the output divisor value is Divisor (7;2) (the upper 6–bits of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) > = 2, then output divisor value is Divisor (3;2) (bits 2 and 3 of the divisor). If Divisor (7;0) < 16 and Divisor (3;2) < 2, then output divisor value is (Divisor (3;2) + 60).

**Figure 36. Analog Test Mode Description**

| TM # | TM 3 | TM 2 | TM 1 | TM 0 | Circuit Blocks Under Test | Input Pin | Output Pin |
|---|---|---|---|---|---|---|---|
| 11 | 1 | 0 | 1 | 1 | Compressor | C In | $T_X$ In |
| 12 | 1 | 1 | 0 | 0 | Not Used | N/A | N/A |
| 13 | 1 | 1 | 0 | 1 | ALC Gain = 10 Option | N/A | N/A |
| 14 | 1 | 1 | 1 | 0 | ALC Gain = 25 Option | N/A | N/A |
| 15 | 1 | 1 | 1 | 1 | Not Used | N/A | N/A |

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### Test Modes

Digital and analog test modes can be selected through the 4–bit Test Mode Register. In digital test mode, the "$T_X$ $V_{CO}$" input pin is multiplexed to the input of the counter under test and the output of the counter under test is multiplexed to the "Clk Out" output pin so that each counter can be individually tested. Make sure test mode bits are set to "0's" for normal operation. Digital test mode operation is described in Figure 35. During normal operation and when testing the $T_X$ Prescaler, the "$T_X$ VCO" input can be a minimum of 200 mVpp at 80 MHz and should be ac–coupled. For other test modes, input signals should be standard logic levels of 0 to 2.5 V and a maximum frequency of 16 MHz.

The analog test modes enable separate testing of the Compressor blocks as shown in Figure 36. Also, ALC Gain options can be selected through analog test modes.

### Power–Up Defaults for Control and Counter Registers

When the IC is first powered up, all latch registers are initialized to a defined state. The device is initially placed in the Rx mode with all mutes active. The reference counter is set to generate a 5.0 kHz reference frequency from a 10.24 MHz crystal. The switched capacitor filter clock counter is set properly for operation with a 10.24 MHz crystal. The audio mode will come up in an undefined state and must be set to a bit format shown in Figure 26 for proper operation. The $T_X$ and $R_X$ latch registers are set for USA Channel Frequency 21 (Channel 6 for previous FCC 10 Channel Band). Figure 37 shows the initial power–up states for all latch registers.

**Figure 37. Latch Register Power–Up Defaults**

| Register | Count | MSB | | | | | | | | LSB | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| $T_X$ | 9966 | – | – | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| $R_X$ | 7215 | – | – | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| Ref | 2048 | – | – | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mode | N/A | – | 0 | X | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Gain | N/A | – | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 |
| SC | 31 | – | – | – | – | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| Aux | N/A | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**NOTE:** Bits 6 and 7 in the SC latch register must be set to "1" after power–up for proper operation.

## APPLICATIONS INFORMATION

### Evaluation PC Board

The PCB should be double sided with a full ground plane on one side; any leaded components are inserted on the ground plane side. This affords shielding and isolation from the circuit side of the PCB. The other side is the circuit side which has the interconnect traces and the surface mount components. In cases where cost allows, it may be benificial to use multi layer boards.

The placement of certain components specified in the application circuits is very critical. These components should be placed first and the other less critical components are fitted in last. In general, all RF paths should be kept as short as possible, ground pins should be grounded at the pins and $V_{CC}$ pins should have adequate decoupling to ground at the pins. In mixed mode systems where digital and RF/Analog circuitry are present, the $V_{EE}$ and $V_{CC}$ busses are isolated ac –wise from each other.

### Component Selection

The evaluation PC board is designed to accommodate specific components, while in some cases it is versatile enough to use components from various manufacturers and coil types. The application circuit schematics specify particular components that were used to achieve the results shown in the typical curves and tables, but alternate components should give similar results.

The MC13111 IC is capable of matching the sensitivity, IMD, adjacent channel rejection, and other performance criteria of a multi–chip analog cordless telephone system. For the most part, the same external components are used as in the multi–chip solution. In the following discussion, various parts of the system are analyzed for best peformance and cost tradeoffs. Specific recommendations are made where certain components or circuit designs offer superior performance. The system analyzed is the USA "CT–1" cordless phone. (CT–0 is a similar cordless application in Europe.)

### Input Matching/Sensitivity

The sensitivity of the IC is typically 0.56 μVrms matched with no preamp. To achieve suitable system performance, a preamp and passive duplexer must be used. In production final test, each section of the IC is separately tested to guarantee its system performance in the specific application. The preamp and duplexer (differential, matched input) yields typically –114 dBm 12 dB SINAD sensitivity performance under full duplex operation.

The duplexer is important to achieve full duplex operation without significant "de–sensing" of the receiver by the transmitter. The combination of the duplexer and preamp circuit will attenuate the transmitter power to the receiver by over 60 dB. This will improve the receiver system noise figure without giving up too much IMD intermodulation performance.

The duplexer may be a single piece unit offered by Shimida and Sansui products (designed for 10 channel CT–1 cordless phone) or a two piece solution offered by Toko (designed for 25 channel operation). The duplexer frequency response at the receiver port has a notch at the transmitter frequency band of about 35 to 40 dB with a 2.0 to 3.0 dB insertion loss at the receiver frequency band.

The preamp circuit utilizes a tuned transformer at the output side of the amplifier. This transformer is designed to bandpass filter at the receiver input frequency while rejecting the transmitter frequency. The tuned preamp also improves the noise performance by reducing the bandwidth of the pass band and reducing the second stage contribution of the 1st mixer. The preamp is biased at about 1.0 mA and 3.0 Vdc which yields suitable noise figure and gain.

### Mixers

The 1st and 2nd mixers are similar in design. Both are double balanced to suppress the LO and the input frequencies to give only the sum and difference frequencies out. Typically the LO is suppressed about 40 to 60 dB. The 1st mixer may be driven either differentially or single ended. The gain of the 1st mixer has a 3.0 dB corner at 20 MHz and is used at a 10.7 MHz IF. It has an output impedance of 330 Ω and matches to a typical 10.7 MHz ceramic filter with a source and load impedance of 330 Ω. A series resistor may be used to raise the impedance for use with crystal filters which typically have an input impedance much greater than 330 Ω. The 2nd mixer input impedance is typically 3.0 kΩ; it requires an external 360 Ω parallel resistor for use with a standard 330 Ω 10.7 MHz ceramic filter. The second mixer output impedance is 1.5 kΩ making it suitable to match 455 kHz ceramic filters.

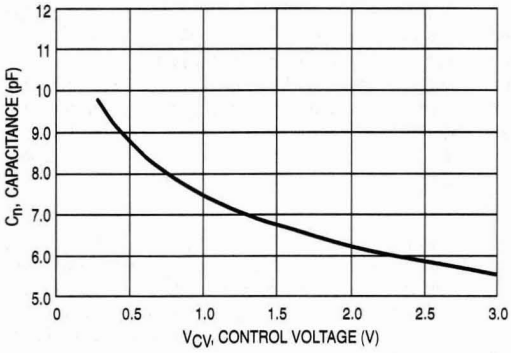
The following table is a list of typical input impedances over frequency for the 1st Mixer. Rp and Cp are represented in parallel form.

| Frequency (MHz) | Rp (Ω) | Cp (pF) |
|---|---|---|
| 20 | 977.7 | 2.44 |
| 25 | 944.3 | 2.60 |
| 30 | 948.8 | 2.65 |
| 35 | 928 | 2.55 |
| 40 | 900 | 2.51 |
| 45 | 873.4 | 2.65 |
| 50 | 859.3 | 2.72 |
| 55 | 821 | 2.72 |
| 60 | 795 | 2.74 |

### First Local Oscillator

The 1st LO is a multi–vibrator oscillator that takes an external capacitance and inductance. It is voltage controlled to an internal varactor from an external loop filter and an on–board phase–lock loop (PLL). The schematic in Figure 33 shows all the basic parasitic elements of the internal circuitry. The 1st LO internal component values have a tolerance of 15%. A typical dc bias level on the LO Input and LO Output is 0.45 Vdc. The temperature coefficient of the varactor is +0.09%/°C. The curve in Figure 38 is the varactor control voltage range as it relates to capacitance. It represents the expected capacitance for a given control voltage of the MC13111.

**Figure 38. First Local Oscillator Varacter versus Control Voltage**




### Second Local Oscillator

The 2nd LO is a CMOS oscillator similar to that used in the MC145162. The 2nd LO is also used as the PLL reference oscillator. It is designed to utilize an external parallel resonant crystal.

### PLL Design

The 1st LO level is important, as well as the choice of the crystal for the PLL clock reference and 2nd LO. A fundamental, parallel resonant crystal specified with 7.0 to 12 pF load calibration capacitance is recommended. If the load calibration capacitance is too high, the crystal locks up very slowly. If the LO power is less than –10 dBm, a pull–down resistor at the 1st LO emitter (Pin 41) will increase its drive level. The LO level is primarily a function of the Colpitts capacitive voltage divider formed by the capacitors between the base to emitter and the emitter to ground.

The VCO gain factor expressed in MHz/V is indeed critical to the phase noise performance. If this curve is too steep or too sensitive to changes in control voltage, it may degrade the phase noise performance. The external VCO circuit design needs to consider the typical swing of the control voltage and the corresponding linearity of the transfer function, $\Delta f_{osc}/\Delta V_{control}$. In general, the higher the Q of the VCO circuit inductor, the better phase noise performance.

Adjacent channel rejection and isolation between the 1st and 2nd mixers may be adversely affected due to layout problems and difficulty in getting up close to the package pins with the grounds and decoupling capacitors on the RF $V_{CC}$. These system parameters must be evaluated for sensitivity to layout and external component placement.

Intermodulation and adjacent channel performance problems may also result from spurs around the 1st LO. This may be caused by harmonics from the switched capacitor clock driver and too low 1st LO drive level. The clock driver operates at a frequency which is f(2nd LO)/(2 * (SCF Divider)). The harmonics are n * (f(2nd LO)), where n can be any positive integer. The current spikes of the SCF on the supply lines cause the disturbance of the 1st LO. This may be verified by observing the spurs on a spectrum analyzer while changing the clock divider value. The spur frequencies will change when the divider value is changed. The spurious sideband problem may be avoided by changing the clock divider value via software for each channel where it is a problem. Certain channels are worse than others. Refer to the MC145162 data sheet for PLL design example.

### Limiting IF Amplifiers

The limiting IF amplifier typically has about 110 dB of gain; the frequency response starts rolling off at 1.0 MHz. Decoupling capacitors should be placed close to Pins 31 and 32 to ensure low noise and stable operation. The IF input impedance is 1.5 kΩ for a suitable match to 455 kHz ceramic filters.

### RSSI/Carrier Detect

The Received Signal Strength Indicator (RSSI) indicates the strength of the IF level and the output is proportional to the logarithm of the IF input signal magnitude. The RSSI dynamic range is typically 80 dB. Connect 0.01 µF to GND from "RSSI" output pin to form the carrier detect filter. A resistor needed to convert the RSSI current to voltage is included in the internal circuit. An internal temperature compensated reference current also improves the RSSI accuracy over temperature.

"CD Out" is an open collector output; thus, an external 100 kΩ pull–up resistor to $V_{CC}$ is recommended. The carrier detect threshold is programmable through the MPU interface.

**Quadrature Detector**

The quadrature detector is coupled to the IF with an external capacitor between Pins 27 and 28; thus, the recovered signal level output is increased for a given bandwidth by increasing the capacitor. The external quadrature component may be either a LCR resonant circuit, which may be adjustable, or a ceramic resonator which is usually fixed tuned.

The bandwidth performance of the detector is controlled by the loaded Q of the LC tank circuit. The following equation defines the components which set the detector circuit's bandwidth:

$$(1)\quad R_T = Q\,X_L$$

where $R_T$ is the equivalent shunt resistance across the LC Tank. $X_L$ is the reactance of the quadrature inductor at the IF frequency ($X_L = 2\pi fL$).

Specific 455 kHz quadrature LC components are manufactured by Toko in various 5 mm, 7 mm and 10 mm shielded cans in surface mount or leaded packages. Recommended components such as, the 7 mm Toko, is used in the application circuit. When minaturization is a key constraint, a surface mount inductor and capacitor may be chosen to form a resonant LC tank with the PCB and parasitic device capacitance. The 455 kHz IF center frequency is calculated by

$$(2)\quad f_c = [2\pi\,(LC_p)^{1/2}] - 1$$

where L is the parallel tank inductor. $C_p$ is the equivalent parallel capacitance of the parallel resonant tank circuit.

The following is a design example for a detector at 455 kHz and a specific loaded Q. The loaded Q of the quadrature detector is chosen somewhat less than the Q of the IF bandpass. For an IF frequency of 455 kHz and an IF bandpass of 20 kHz, the IF bandpass Q is approximately 23; the loaded Q of the quadrature tank is chosen at 15.

Example:

Let the total external C = 180 pF. Note: the capacitance may be split between a 150 pF chip capacitor and a 5.0 to 25 pF variable capacitor; this allows for tuning to compensate for component tolerance. Since the external capacitance is much greater than the internal device and PCB parasitic capacitance, the parasitic capacitance may be neglected.

Rewrite equation (2) and solve for L:

$L = (0.159)^2/(C\,fc^2)$
$L = 678\ \mu H$ ; Thus, a standard value is chosen:
$L = 680\ \mu H$ (surface mount inductor)

The value of the total damping resistor to obtain the required loaded Q of 15 can be calculated from equation (1):

$R_T = Q(2\pi fL)$
$R_T = 15\ (2\pi)(0.455)(680) = 29.5\ k\Omega$

The internal resistance, $R_{int}$ at the quadrature tank Pin 27 is approximately 100 kΩ and is considered in determining the external resistance, $R_{ext}$ which is calculated from

$R_{ext} = ((R_T)(R_{int}))/(R_{int} - R_T)$
$R_{ext} = 41.8\ k\Omega$; Thus, choose the standard value:
$R_{ext} = 39\ k\Omega$

A ceramic discriminator is recommended for the quadrature circuit in applications where fixed tuning is desired. The ceramic discriminator and a 22 k resistor are placed from Pin 27 to $V_{CC}$. A 10 pF capacitor is placed from Pin 28 to 27 to properly drive the discriminator.

MuRata Erie has designed a resonator that is compatible with the IC. For US applications the part number is CDBM455C48. For Europe the part number is CDBM450C48. Contact Motorola Analog Marketing for performance data using muRata's parts.

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**Figure 39a. Baseset RF Applications Circuit**

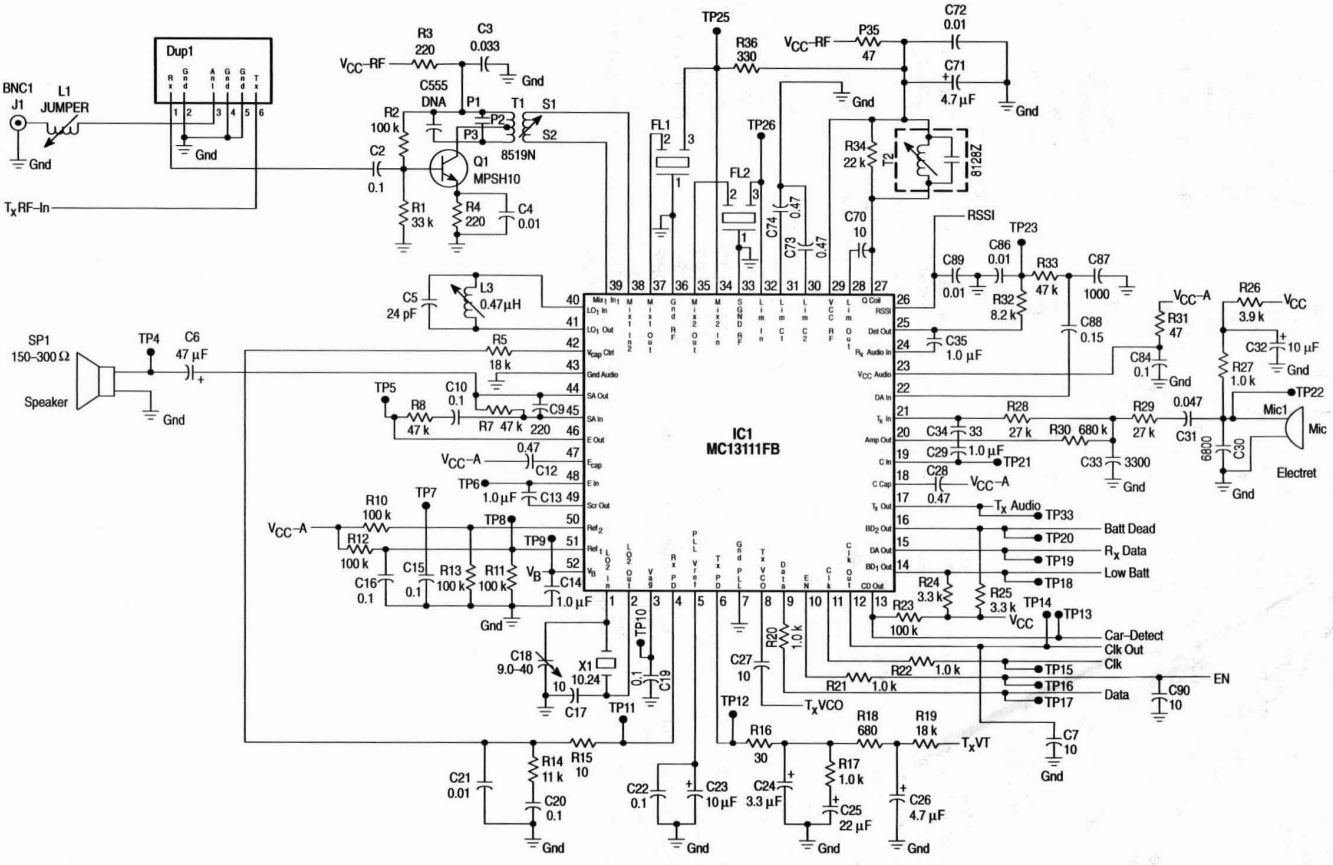
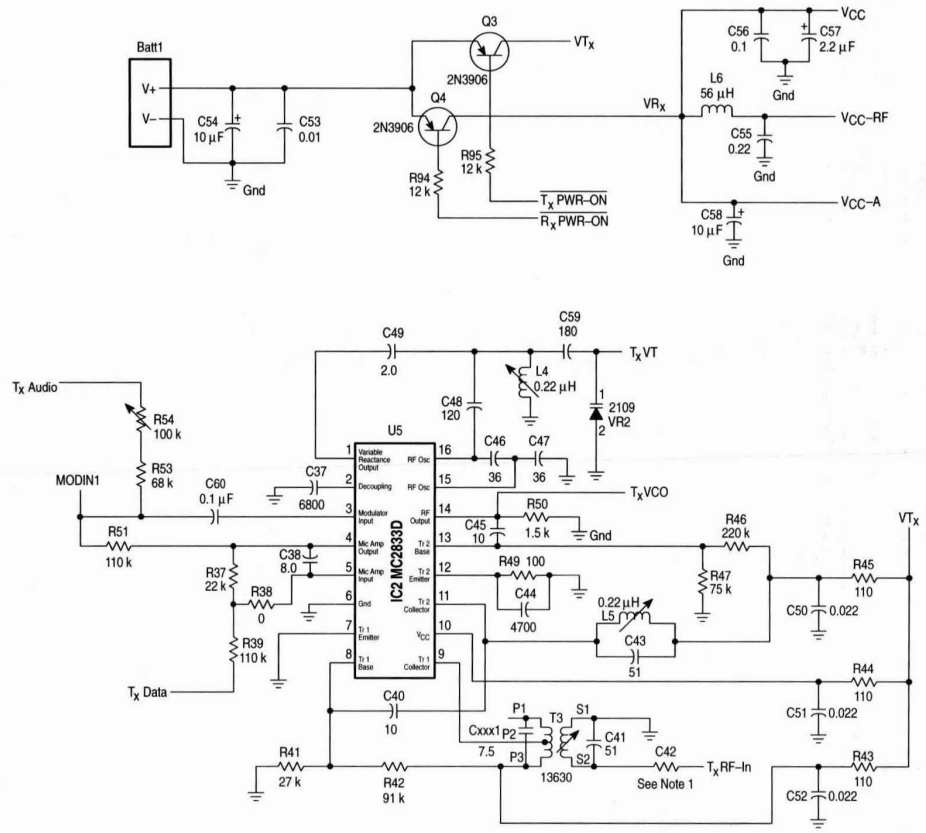
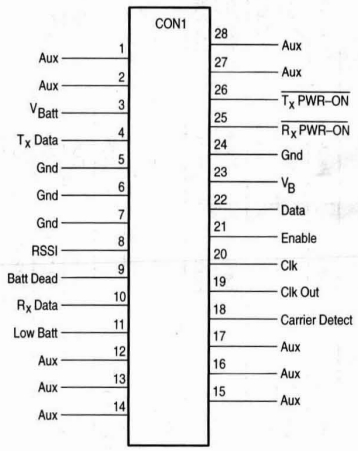


**Figure 39a. Baseset RF Applications Circuit (continued)**




NOTE 1: C42 = X42 = 51 Ω

## APPENDIX B – MC13111 APPLICATION BOARD BILL OF MATERIAL (USA)

| Reference | Description | Value | Package | Part Number | Vendor |
|---|---|---|---|---|---|
| X1 | 10.24 Crystal (Load Cap <12 pF) | – | HC49US | AAL10M240000FLE10A | Standard Crystal |
| VR2 | Diode | – | Sot23 | MMBV2109LT1 | Motorola |
| DUP1 | Duplexer (25 Channel) | Baseset | Hybrid | DPX1035 75B–153B | Sumida |
| DUP1 | Duplexer (25 Channel) | Handset | Hybrid | DPX1035 75B–154B | Sumida |
| FL1 | 10.7 MHz Filter (Red Dot) | – | – | SFE10.7MS2–A | muRata |
| FL2 | 455 kHz Filter | – | – | CFU455E2 | muRata |
| IC1 | Universal Cordless Telephone IC | – | QFP | MC13111FB | Motorola |
| IC2 | FM Transmitter IC | – | SO–16 | MC2833D | Motorola |
| L3 | Inductor | 0.47 µH | Can | 292SNS–T1370Z | Toko |
| L4/L5 | Inductor | 0.22 µH | Can | 292SNS–T1368Z | Toko |
| T1/T3 | Transformer | – | Can | 600GCS–8519N | Toko |
| T2 | Quadrature Coil | – | Can | 7MCS–8128Z | Toko |
| Q1 | Transistor | – | TO–92 | MPSH10 | Motorola |
| Q3 | Transistor | – | TO–92 | 2N3906 | Motorola |
| Q4 | Transistor | – | TO–92 | 2N3906 | Motorola |

**NOTE:** Components for the Handset and Baseset are the same, except where noted on the Bill of Material and Schematic.

## APPENDIX C – MEASUREMENT OF COMPANDOR ATTACK/DECAY TIME

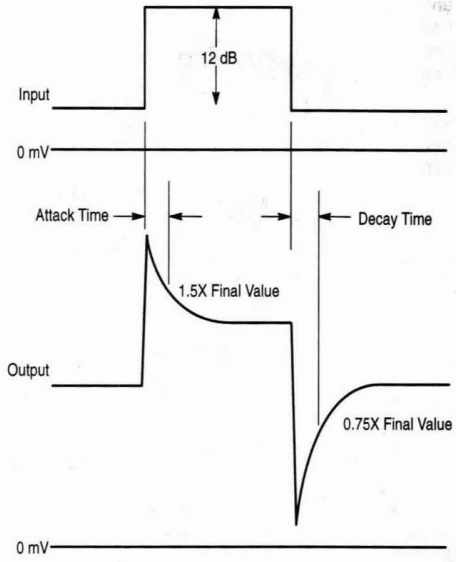
This measurement definition is based on EIA/CCITT recommendations.

### Compressor Attack Time

For a 12 dB step up at the input, attack time is defined as the time for the output to settle to 1.5X of the final steady state value.

### Compressor Decay Time

For a 12 dB step down at the input, decay time is defined as the time for the input to settle to 0.75X of the final steady state value.

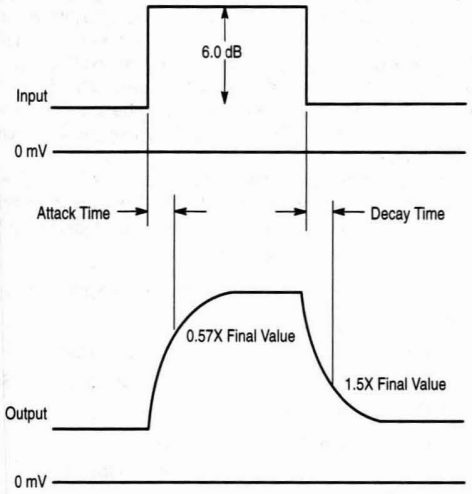



### Expandor Attack

For a 6.0 dB step up at the input, attack time is defined as the time for the output to settle to 0.57X of the final steady state value.

### Expandor Decay

For a 6.0 dB step down at the input, decay time is defined as the time for the output to settle to 1.5X of the final steady state value.




8

MOTOROLA

# FM Communications Receivers

**MC13135**
**MC13136**

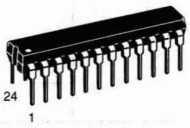
**DUAL CONVERSION NARROWBAND FM RECEIVERS**

The MC13135/MC13136 are the second generation of single chip, dual conversion FM communications receivers developed by Motorola. Major improvements in signal handling, RSSI and first oscillator operation have been made. In addition, recovered audio distortion and audio drive have improved. Using Motorola's MOSAIC™ 1.5 process, these receivers offer low noise, high gain and stability over a wide operating voltage range.

Both the MC13135 and MC13136 include a Colpitts oscillator, VCO tuning diode, low noise first and second mixer and LO, high gain limiting IF, and RSSI. The MC13135 is designed for use with an LC quadrature detector and has an uncommitted op amp that can be used either for an RSSI buffer or as a data comparator. The MC13136 can be used with either a ceramic discriminator or an LC quad coil and the op amp is internally connected for a voltage buffered RSSI output.

These devices can be used as stand–alone VHF receivers or as the lower IF of a triple conversion system. Applications include cordless telephones, short range data links, walkie–talkies, low cost land mobile, amateur radio receivers, baby monitors and scanners.

- Complete Dual Conversion FM Receiver – Antenna to Audio Output
- Input Frequency Range – 200 MHz
- Voltage Buffered RSSI with 70 dB of Usable Range
- Low Voltage Operation – 2.0 to 6.0 Vdc (2 Cell NiCad Supply)
- Low Current Drain – 3.5 mA Typ
- Low Impedance Audio Output < 25 Ω
- VHF Colpitts First LO for Crystal or VCO Operation
- Isolated Tuning Diode
- Buffered First LO Output to Drive CMOS PLL Synthesizer




**P SUFFIX**
PLASTIC PACKAGE
CASE 724

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
(SO–24L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13135P | $T_A$ = – 40° to +85°C | Plastic DIP |
| MC13135DW | | SO–24L |
| MC13136P | | Plastic DIP |
| MC13136DW | | SO–24L |

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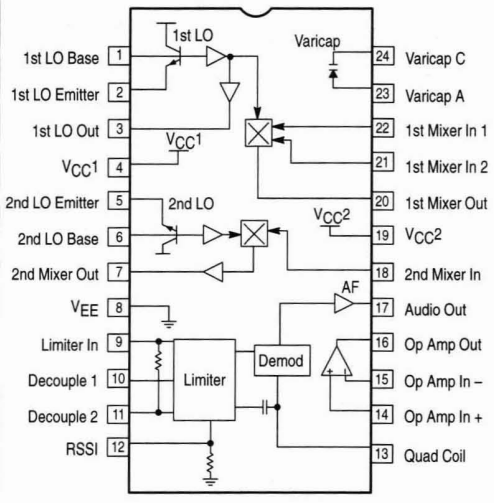
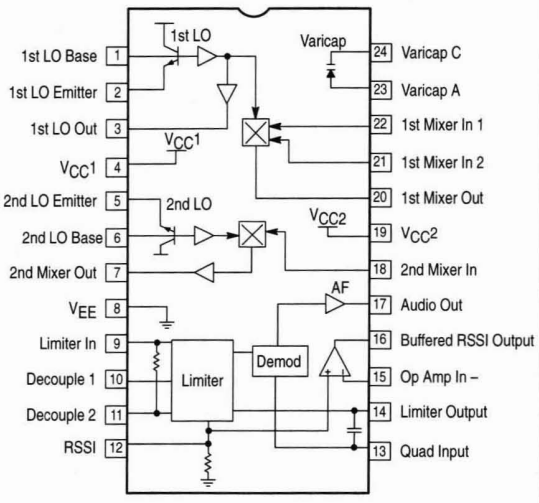
**PIN CONNECTIONS**

**MC13135**




**MC13136**




Each device contains 142 active transistors.

**MAXIMUM RATINGS**

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4, 19 | $V_{CC}$ (max) | 6.5 | Vdc |
| RF Input Voltage | 22 | $RF_{in}$ | 1.0 | Vrms |
| Junction Temperature | – | $T_J$ | +150 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to +150 | °C |

**RECOMMENDED OPERATING CONDITIONS**

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4, 19 | $V_{CC}$ | 2.0 to 6.0 | Vdc |
| Maximum 1st IF | – | $f_{IF1}$ | 21 | MHz |
| Maximum 2nd IF | – | $f_{IF2}$ | 3.0 | MHz |
| Ambient Temperature Range | – | $T_A$ | – 40 to + 85 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$=25°C, $V_{CC}$=4.0 Vdc, $f_o$=49.7 MHz, $f_{MOD}$=1.0 kHz, Deviation=±3.0 kHz, $f_{1stLO}$=39 MHz, $f_{2nd}$ LO = 10.245 MHz, IF1 = 10.7 MHz, IF2 = 455 kHz, unless otherwise noted. All measurements performed in the test circuit of Figure 1.)

| Characteristic | Condition | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Total Drain Current | No Input Signal | $I_{CC}$ | – | 4.0 | 6.0 | mAdc |
| Sensitivity (Input for 12 dB SINAD) | Matched Input | $V_{SIN}$ | – | 1.0 | – | μVrms |
| Recovered Audio<br>MC13135<br>MC13136 | $V_{RF}$ = 1.0 mV | $AF_O$ | <br>170<br>215 | <br>220<br>265 | <br>300<br>365 | mVrms |
| Limiter Output Level<br>(Pin 14, MC13136) | | $V_{LIM}$ | <br>– | <br>130 | <br>– | mVrms |
| 1st Mixer Conversion Gain | $V_{RF}$ = – 40 dBm | $MX_{gain1}$ | – | 12 | – | dB |
| 2nd Mixer Conversion Gain | $V_{RF}$ = – 40 dBm | $MX_{gain2}$ | – | 13 | – | dB |
| First LO Buffered Output | – | $V_{LO}$ | – | 100 | – | mVrms |
| Total Harmonic Distortion | $V_{RF}$ = – 30 dBm | THD | – | 1.2 | 3.0 | % |
| Demodulator Bandwidth | – | BW | – | 50 | – | kHz |
| RSSI Dynamic Range | – | RSSI | – | 70 | – | dB |
| First Mixer 3rd Order Intercept<br>(Input) | <br>Matched<br>Unmatched | $TOI_{Mix1}$ | <br>–<br>– | <br>–17<br>–11 | <br>–<br>– | dBm |
| Second Mixer 3rd Order<br>Intercept (RF Input) | Matched<br>Input | $TOI_{Mix2}$ | <br>– | <br>– 27 | <br>– | dBm |
| First LO Buffer Output Resistance | – | $R_{LO}$ | – | – | – | Ω |
| First Mixer Parallel Input Resistance | – | R | – | 722 | – | Ω |
| First Mixer Parallel Input Capacitance | – | C | – | 3.3 | – | pF |
| First Mixer Output Impedance | – | ZO | – | 330 | – | Ω |
| Second Mixer Input Impedance | – | $Z_I$ | – | 4.0 | – | kΩ |
| Second Mixer Output Impedance | – | ZO | – | 1.8 | – | kΩ |
| Detector Output Impedance | – | ZO | – | 25 | – | Ω |

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## TEST CIRCUIT INFORMATION

Although the MC13136 can be operated with a ceramic discriminator, the recovered audio measurements for both the MC13135 and MC13136 are made with an LC quadrature detector. The typical recovered audio will depend on the external circuit; either the Q of the quad coil, or the RC matching network for the ceramic discriminator. On the MC13136, an external capacitor between Pins 13 and 14 can be used with a quad coil for slightly higher recovered audio. See Figures 10 through 13 for additional information.

Since adding a matching circuit to the RF input increases the signal level to the mixer, the third order intercept (TOI) point is better with an unmatched input (50 Ω from Pin 21 to Pin 22). Typical values for both have been included in the Electrical Characterization Table. TOI measurements were taken at the pins with a high impedance probe/spectrum analyzer system. The first mixer input impedance was measured at the pin with a network analyzer.

**Figure 1a. MC13135 Test Circuit**

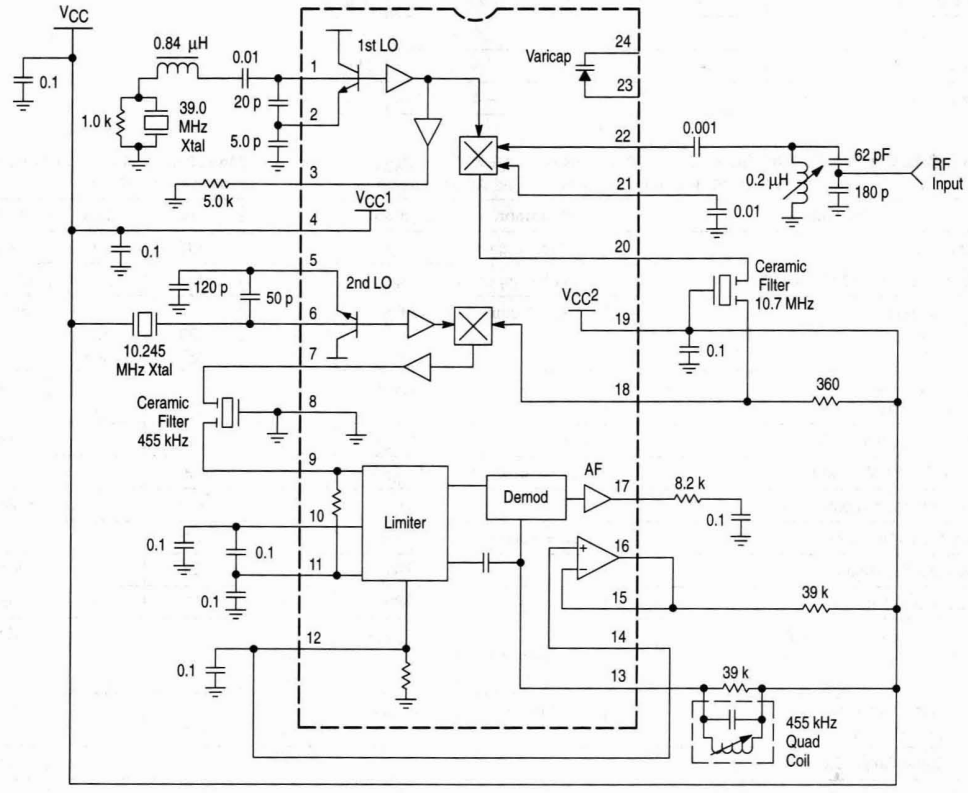


**Figure 1b. MC13136 Quad Detector Test Circuit**

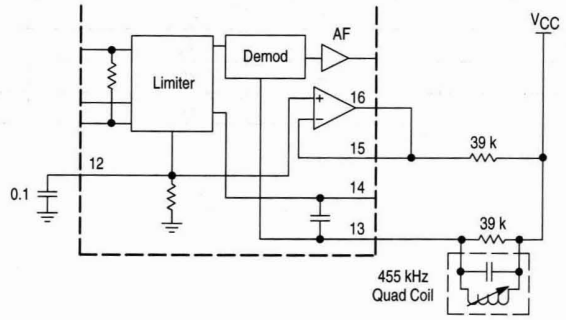

**Figure 2. Supply Current versus Supply Voltage**

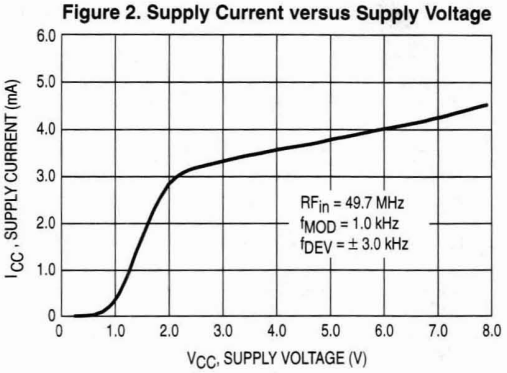


**Figure 3. RSSI Output versus RF Input**

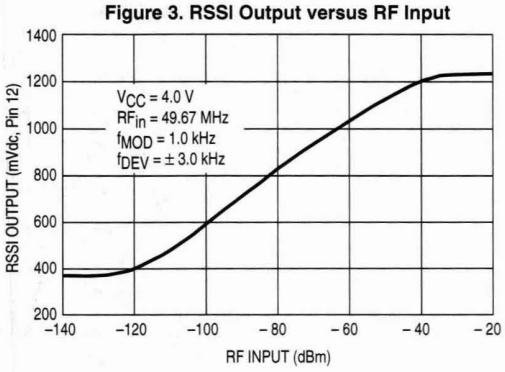


**Figure 4. Varactor Capacitance, Resistance versus Bias Voltage**

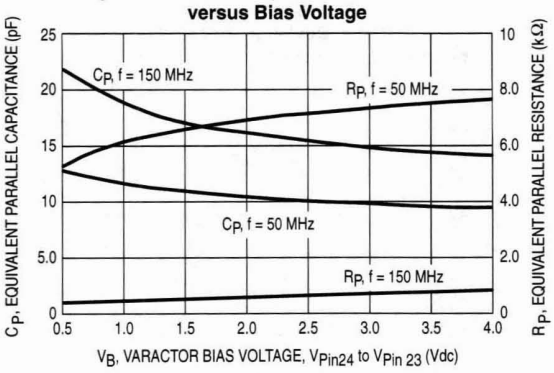
$C_P$, EQUIVALENT PARALLEL CAPACITANCE (pF)
$R_P$, EQUIVALENT PARALLEL RESISTANCE (kΩ)
$V_B$, VARACTOR BIAS VOLTAGE, $V_{Pin24}$ to $V_{Pin\ 23}$ (Vdc)
$C_P$, f = 150 MHz
$R_P$, f = 50 MHz
$C_P$, f = 50 MHz
$R_P$, f = 150 MHz

**Figure 5. Oscillator Frequency versus Varactor Bias**

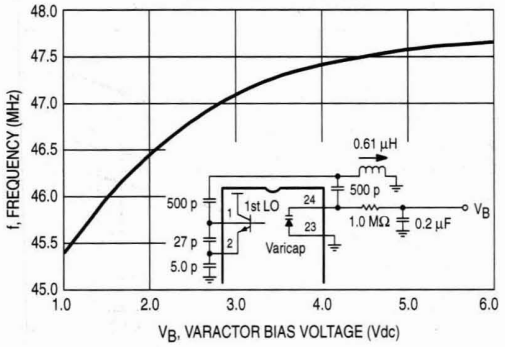


**Figure 6. Signal Levels versus RF Input**

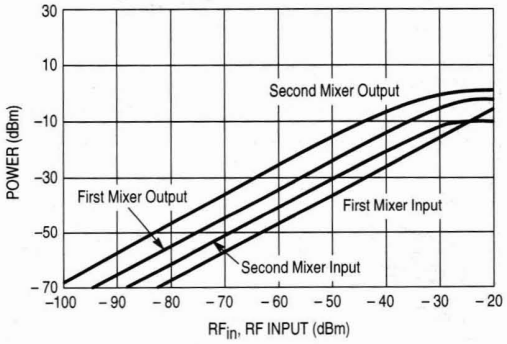


**Figure 7. Signal + Noise, Noise, and AM Rejection versus Input Power**

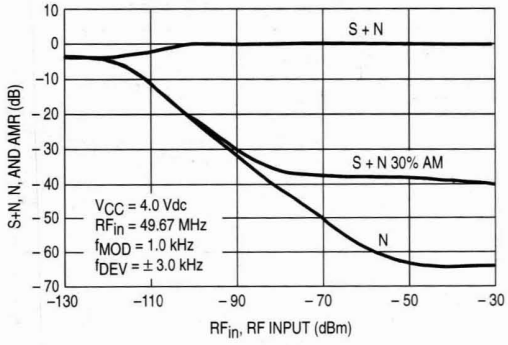


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**Figure 8. Op Amp Gain and Phase versus Frequency**

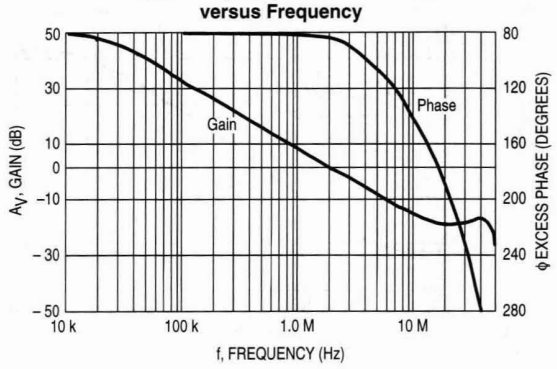



**Figure 9. First Mixer Third Order Intermodulation (Unmatched Input)**

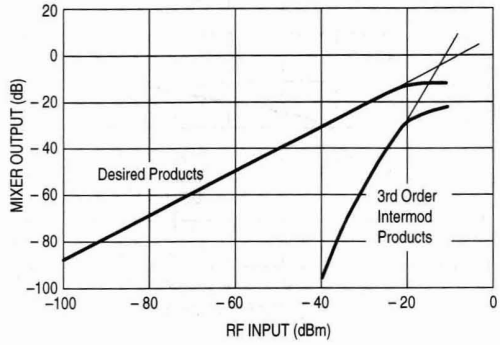



**Figure 10. Recovered Audio versus Deviation for MC13135**

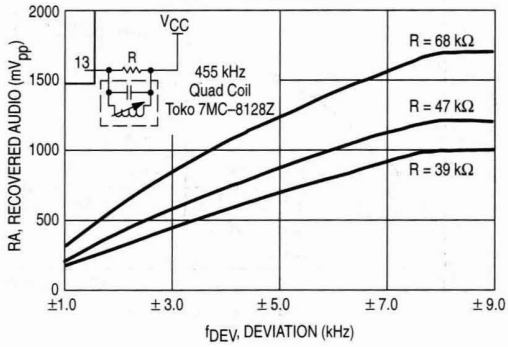



**Figure 11. Distortion versus Deviation for MC13135**

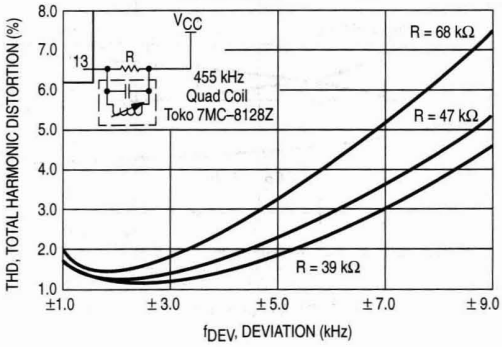



**Figure 12. Recovered Audio versus Deviation for MC13136**

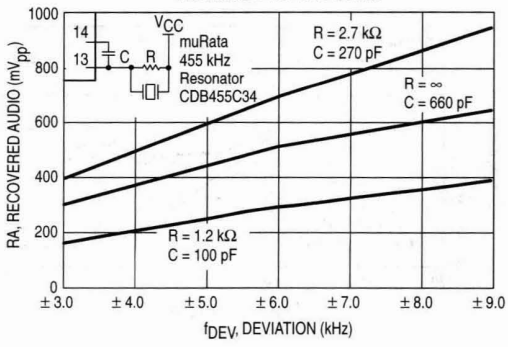
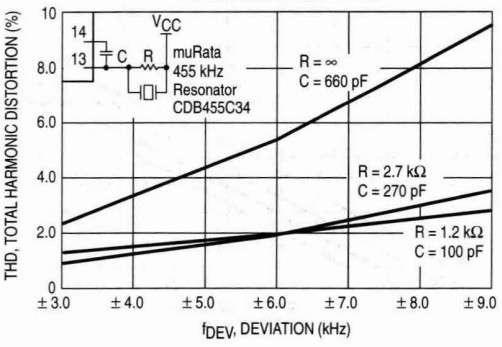



**Figure 13. Distortion versus Deviation for MC13136**

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## CIRCUIT DESCRIPTION

The MC13135/13136 are complete dual conversion receivers. They include two local oscillators, two mixers, a limiting IF amplifier and detector, and an op amp. Both provide a voltage buffered RSSI with 70 dB of usable range, isolated tuning diode and buffered LO output for PLL operation, and a separate $V_{CC}$ pin for the first mixer and LO. Improvements have been made in the temperature performance of both the recovered audio and the RSSI.

### $V_{CC}$

Two separate $V_{CC}$ lines enable the first LO and mixer to continue running while the rest of the circuit is powered down. They also isolate the RF from the rest of the internal circuit.

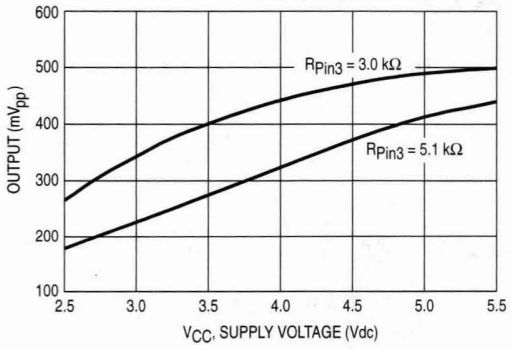
### Local Oscillators

The local oscillators are grounded collector Colpitts, which can be easily crystal–controlled or VCO controlled with the on–board varactor and external PLL. The first LO transistor is internally biased, but the emitter is pinned–out and $I_Q$ can be increased for high frequency or VCO operation. The collector is not pinned out, so for crystal operation, the LO is generally limited to 3rd overtone crystal frequencies; typically around 60 MHz. For higher frequency operation, the LO can be provided externally as shown in Figure 16.

### Buffer

An amplifier on the 1st LO output converts the single–ended LO output to a differential signal to drive the mixer. Capacitive coupling between the LO and the amplifier minimizes the effects of the change in oscillator current on the mixer. Buffered LO output is pinned–out at Pin 3 for use with a PLL, with a typical output voltage of 320 $mV_{pp}$ at $V_{CC}$ = 4.0 V and with a 5.1 k resistor from Pin 3 to ground. As seen in Figure 14, the buffered LO output varies with the supply voltage and a smaller external resistor may be needed for low voltage operation. The LO buffer operates up to 60 MHz, typically. Above 60 MHz, the output at Pin 3 rolls off at approximately 6.0 dB per octave. Since most PLLs require about 200 $mV_{pp}$ drive, an external amplifier may be required.

**Figure 14. Buffered LO Output Voltage versus Supply Voltage**




### Mixers

The first and second mixer are of similar design. Both are double balanced to suppress the LO and input frequencies to give only the sum and difference frequencies out. This configuration typically provides 40 to 60 dB of LO suppression. New design techniques provide improved mixer linearity and third order intercept without increased noise. The gain on the output of the 1st mixer starts to roll off at about 20 MHz, so this receiver could be used with a 21 MHz first IF. It is designed for use with a ceramic filter, with an output impedance of 330 Ω. A series resistor can be used to raise the impedance for use with a crystal filter, which typically has an input impedance of 4.0 kΩ. The second mixer input impedance is approximately 4.0 kΩ; it requires an external 360 Ω parallel resistor for use with a standard ceramic filter.

### Limiting IF Amplifier and Detector

The limiter has approximately 110 dB of gain, which starts rolling off at 2.0 MHz. Although not designed for wideband operation, the bandwidth of the audio frequency amplifier has been widened to 50 kHz, which gives less phase shift and enables the receiver to run at higher data rates. However, care should be taken not to exceed the bandwidth allowed by local regulations.

The MC13135 is designed for use with an LC quadrature detector, and does not have sufficient drive to be used with a ceramic discriminator. The MC13136 was designed to use a ceramic discriminator, but can also be run with an LC quad coil, as mentioned in the Test Circuit Information section. The data shown in Figures 12 and 13 was taken using a muRata CDB455C34 ceramic discriminator which has been specially matched to the MC13136. Both the choice of discriminators and the external matching circuit will affect the distortion and recovered audio.

### RSSI/Op Amp

The Received Signal Strength Indicator (RSSI) on the MC13135/13136 has about 70 dB of range. The resistor needed to translate the RSSI current to a voltage output has been included on the internal circuit, which gives it a tighter tolerance. A temperature compensated reference current also improves the RSSI accuracy over temperature. On the MC13136, the op amp on board is connected to the output to provide a voltage buffered RSSI. On the MC13135, the op amp is not connected internally and can be used for the RSSI or as a data slicer (see Figure 17c).

**Figure 15. PLL Controlled Narrowband FM Receiver at 46/49 MHz**

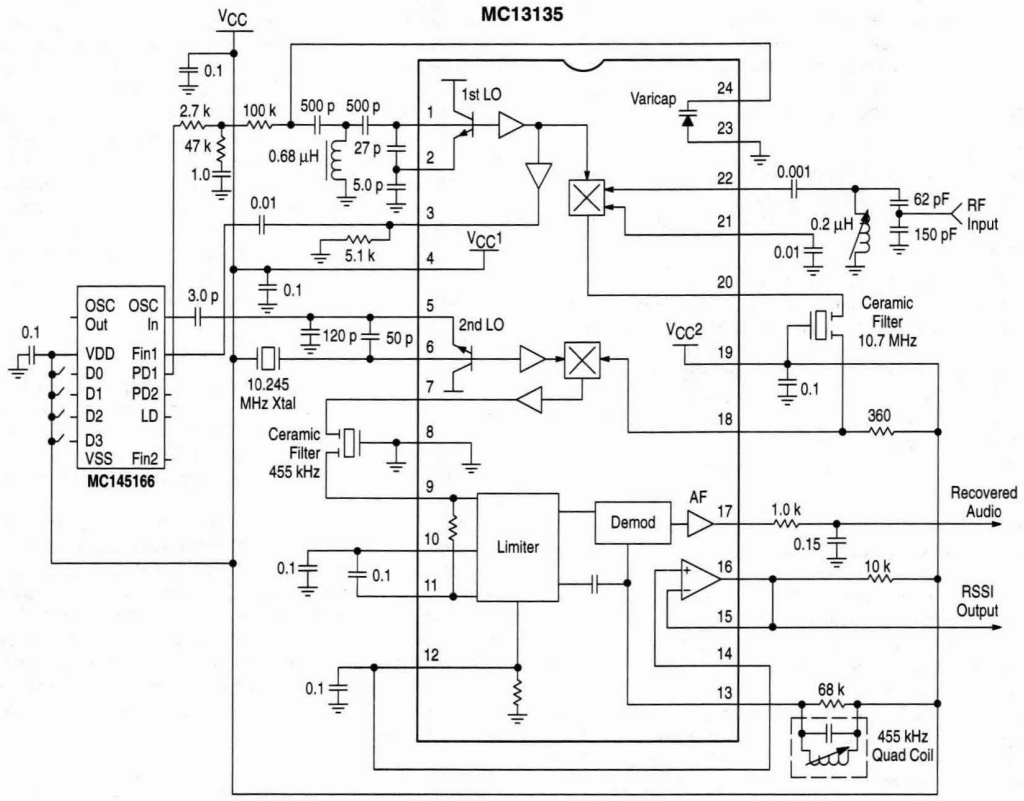
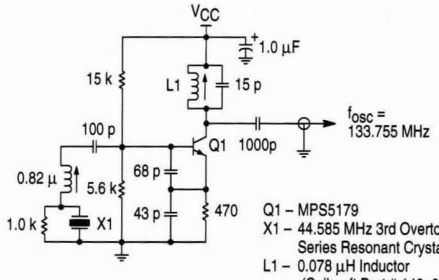


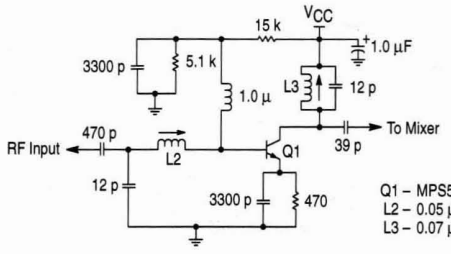

**Figure 16. 144 MHz Single Channel Application Circuit**

**1st LO External Oscillator Circuit**




Q1 – MPS5179
X1 – 44.585 MHz 3rd Overtone Series Resonant Crystal
L1 – 0.078 µH Inductor (Coilcraft Part # 146–02J08)

**Preamp for MC13135 at 144.455 MHz**




Q1 – MPS5179
L2 – 0.05 µH
L3 – 0.07 µH

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**Figure 17a. Single Channel Narrowband FM Receiver at 49.7 MHz**

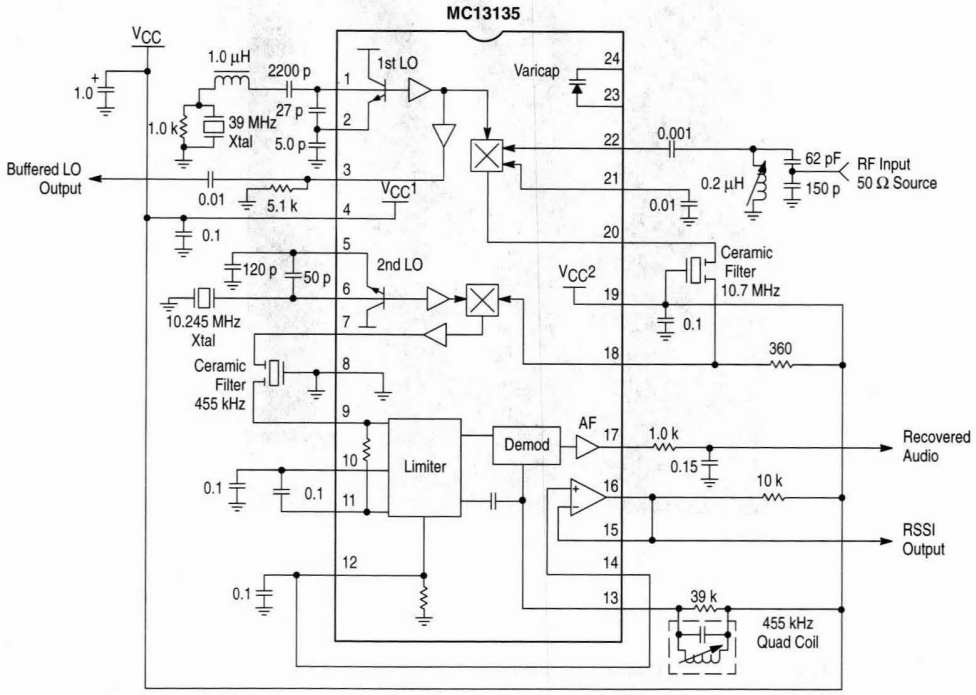
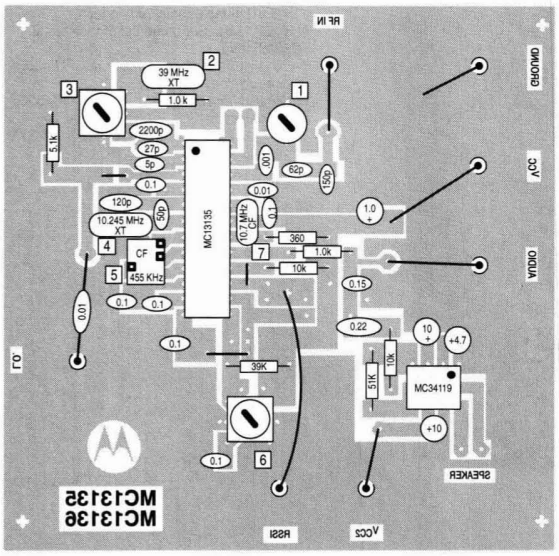



**Figure 17b. PC Board Component View**




**NOTES:** 1. 0.2 µH tunable (unshielded) inductor
2. 39 MHz Series mode resonant 3rd Overtone Crystal
3. 1.5 µH tunable (shielded) inductor
4. 10.245 MHz Fundamental mode crystal, 32 pF load
5. 455 kHz ceramic filter, muRata CFU 455B or equivalent
6. Quadrature coil, Toko 7MC–8128Z (7mm) or Toko RMC–2A6597HM (10mm)
7. 10.7 MHz ceramic filter, muRata SFE10.7MJ–A or equivalent

**Figure 17c. Optional Data Slicer Circuit**
(Using Internal Op Amp)

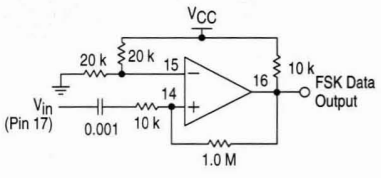



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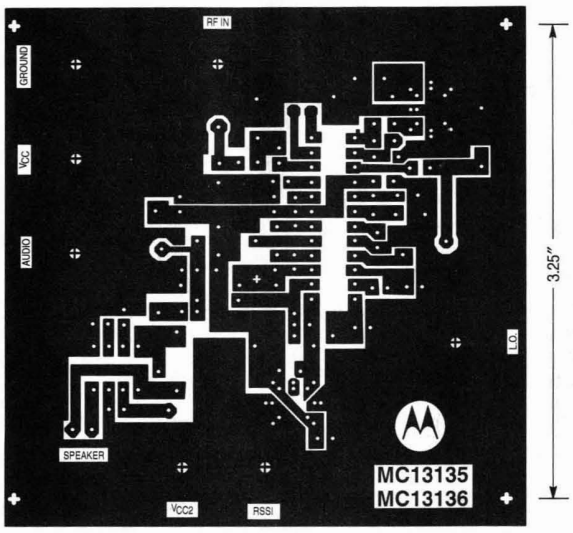
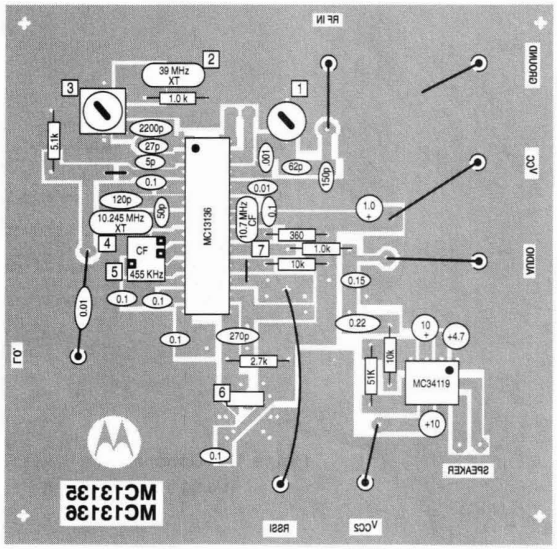
**Figure 18. PC Board Solder Side View**




(Circuit Side View)

8

**Figure 19. PC Board Component View**




**NOTES:** 1. 0.2 µH tunable (unshielded) inductor
2. 39 MHz Series mode resonant 3rd Overtone Crystal
3. 1.5 µH tunable (shielded) inductor
4. 10.245 MHz Fundamental mode crystal, 32 pF load
5. 455 kHz ceramic filter, muRata CFU 455B or equivalent
6. Ceramic discriminator, muRata CDB455C34 or equivalent
7. 10.7 MHz ceramic filter, muRata SFE10.7MJ–A or equivalent

**Figure 20a. Single Channel Narrowband FM Receiver at 49.7 MHz**

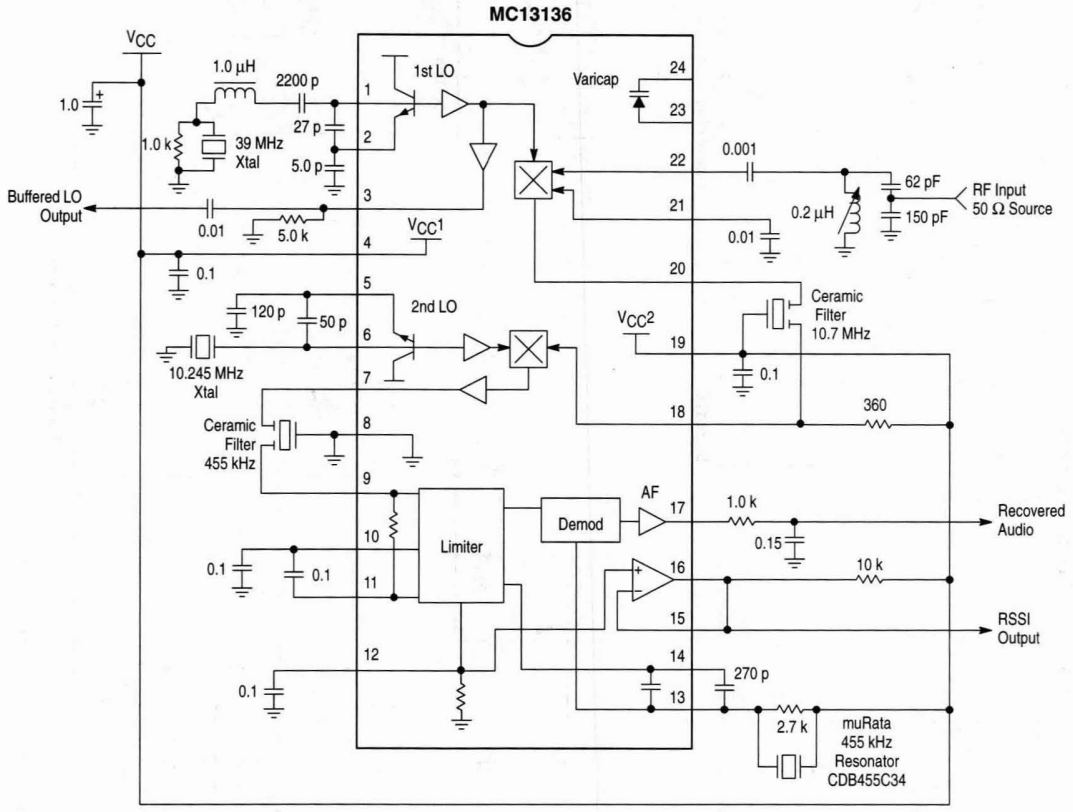



**Figure 20b. Optional Audio Amplifier Circuit**

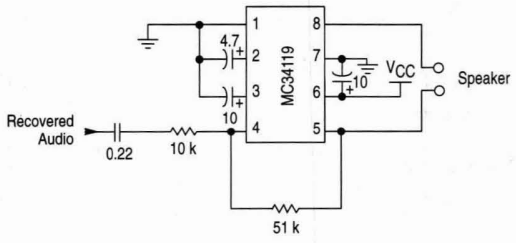



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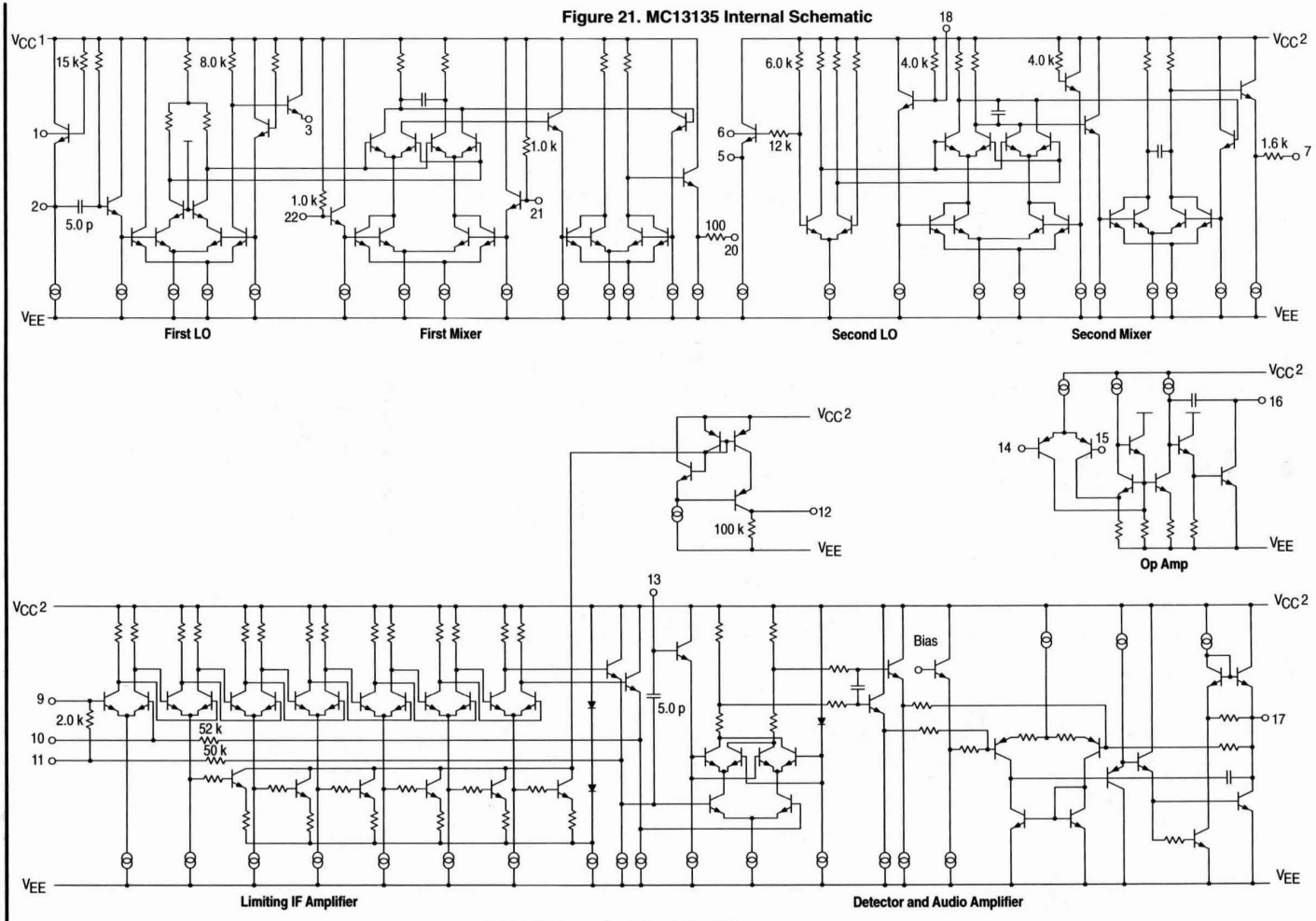
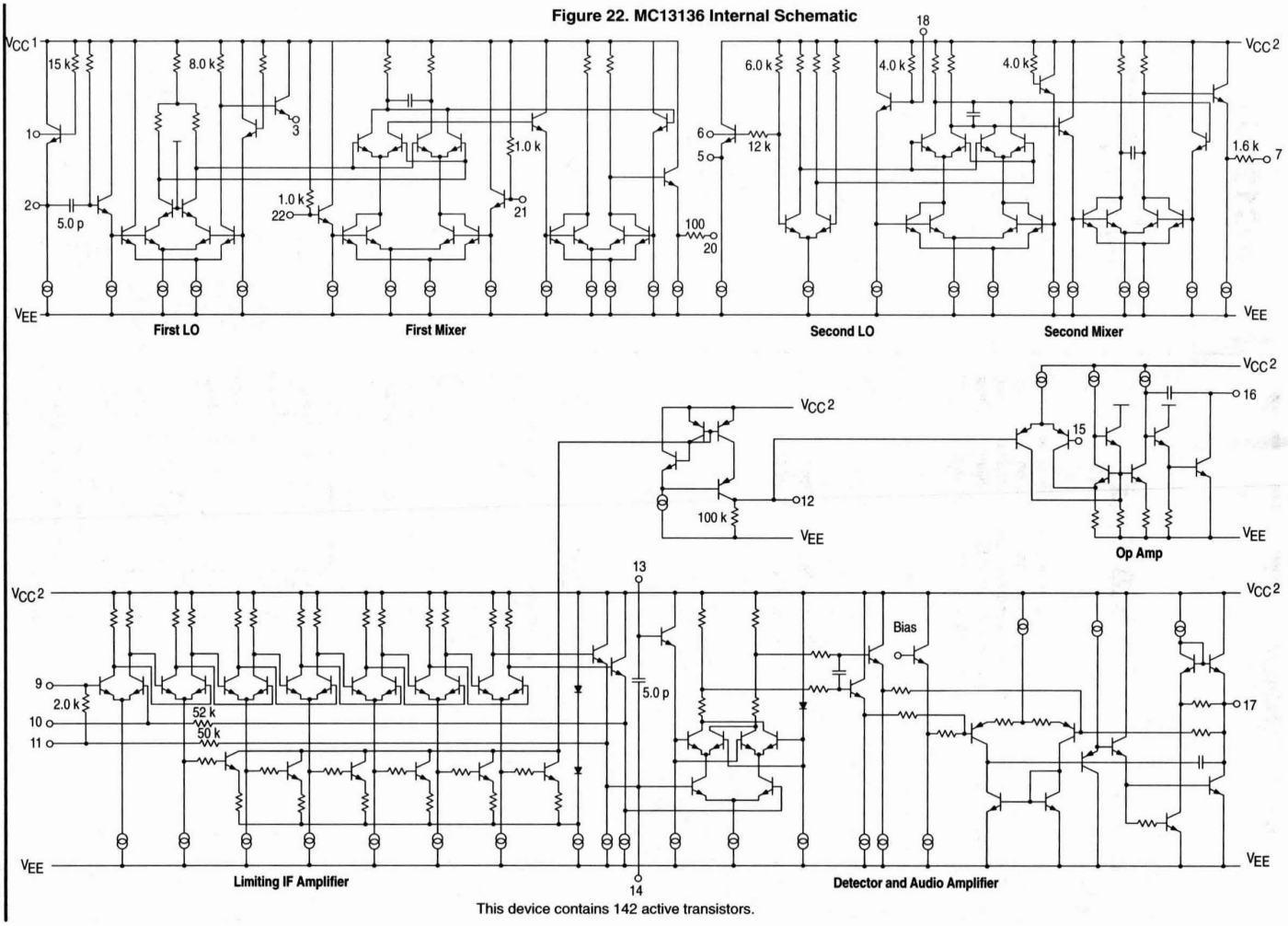
**Figure 21. MC13135 Internal Schematic**




This device contains 142 active transistors.

**Figure 22. MC13136 Internal Schematic**




This device contains 142 active transistors.

MOTOROLA

# MC13141

*Product Preview*

## Low Power DC - 1.8 GHz LNA and Mixer

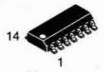
**LOW POWER DC – 1.8 GHz LNA AND MIXER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13141 is intended to be used as a first amplifier and down converter for RF applications. It features wide band operation, low noise, high gain and high linearity while maintaining low current consumption. The circuit consists of a Low Noise Amplifier (LNA), a Local Oscillator amplifier ($LO_{amp}$), a mixer, an Intermediate Frequency amplifier ($IF_{amp}$) and a dc control section.

- Wide RF Bandwidth: DC–1.8 GHz
- Wide Mixer Bandwidth: DC–1.8 GHz
- Wide IF Bandwidth: DC–100 MHz
- Low Power: 7.7 mA @ $V_{CC}$ = 2.7–6.5 V
- High Mixer Linearity: $Pi_{1.0\ dB}$ = –2.0 dBm, $IP_{3in}$ = 3.0 dBm
- Linearity Adjustment Increases $IP_{3in}$ (Not Available in SOIC8) Up to +20 dBm
- Single–Ended 50 Ω Mixer Input
- Double Balanced Mixer Operation
- Single–Ended 800 Ω Mixer Output
- Single–Ended 50 Ω LO Input

**D1 SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**FTB SUFFIX**
PLASTIC PACKAGE
CASE 976
(Thin QFP)

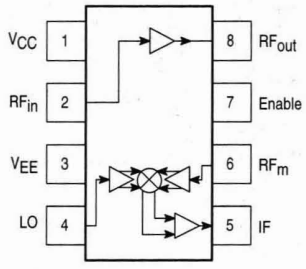
8

**ORDERING INFORMATION**

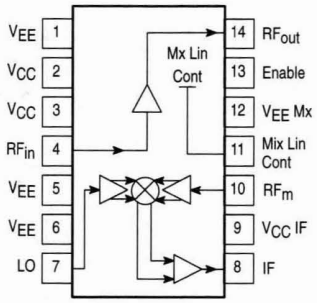
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13141D1 | $T_A$ = –40° to +85°C | SO–8 |
| MC13141D | | SO–14 |
| MC13141FTB | | TQFP–20 |

**PIN CONNECTIONS**

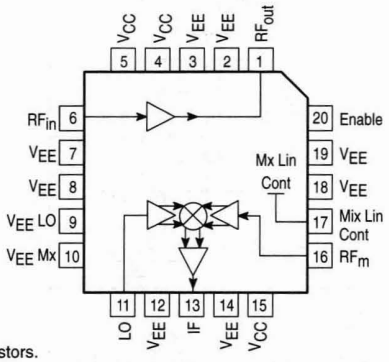
SO–8




SO–14




TQFP–20




This device contains 161 active transistors.

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 (max) | Vdc |
| Operating Supply Voltage Range | $V_{CC}$ | 2.7–6.5 | Vdc |

**ELECTRICAL CHARACTERISTICS** (SOIC8 Package, $V_{CC}$ = 3.0 V, $T_A$ = 25°C, $LO_{in}$ = –10 dBm @ 950 MHz, IF @ 50 MHz.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current (Power Down) | $I_{CC}$ | – | 100 | – | pA |
| Supply Current (Power Up) | $I_{CC}$ | – | 7.7 | – | mA |
| Amplifier Gain (50 Ω Insertion Gain) | S21 | – | 12 | – | dB |
| Amplifier Reverse Isolation | S12 | – | –33 | – | dB |
| Amplifier Input Match | $\Gamma_{in\ amp}$ | – | –10 | – | dB |
| Amplifier Output Match | $\Gamma_{out\ amp}$ | – | –15 | – | dB |
| Amplifier 1.0 dB Gain Compression | $Pin_{-1.0\ dB}$ | – | –15 | – | dBm |
| Amplifier Input Third Order Intercept | $IP3_{in}$ | – | – 5.0 | – | dBm |
| Amplifier Gain @ N.F. (Application Circuit) | $G_{NF}$ | – | 17 | – | dB |
| Amplifier Noise Figure (50 Ω) | NF | – | 1.8 | – | dB |
| Mixer Voltage Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $VG_C$ | – | 15 | – | dB |
| Mixer Power Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $PG_C$ | – | 7.0 | – | dB |
| Mixer Input Match | $\Gamma_{in\ M}$ | – | –20 | – | dB |
| Mixer SSB Noise Figure | $NF_{SSBM}$ | – | 16.0 | – | dB |
| Mixer 1.0 dB Gain Compression | $Pin_{-1.0\ dBM}$ | – | –10 | – | dBm |
| Mixer Input Third Order Intercept | $IP3_{inM}$ | – | –3.0 | – | dBm |
| Mixer 3 dB RF Bandwidth | $M_{x-3\ dBBW}$ | – | 1.8 | – | GHz |
| LO Drive Level | $LO_{In}$ | – | –10 | – | dBm |
| LO Input Match | $\Gamma_{in\ LO}$ | – | –20 | – | dB |
| $RF_{in}$ Feedthrough to $RF_m$ | $P_{RFin–RFin}$ | – | –13 | – | dB |
| $RF_{out}$ Feedthrough to $RF_m$ | $P_{RFout–RFm}$ | – | –30 | – | dB |
| LO Feedthrough to IF | $P_{LO–IF}$ | – | –25 | – | dB |
| LO Feedthrough to $RF_{in}$ | $P_{LO–RFin}$ | – | –30 | – | dB |
| LO Feedthrough to $RF_m$ | $P_{LO–RFm}$ | – | –50 | – | dB |
| Mixer RF Feedthrough to IF | $P_{RFm–IF}$ | – | –50 | – | dB |
| Mixer RF Feedthrough to $RF_{in}$ | $P_{RFm–RFin}$ | – | –25 | – | dB |

8

## CIRCUIT DESCRIPTION

### General

The MC13141 is a low power LNA, double–balanced mixer. This device is designated for use as the front–end section in analog and digital FM systems such as Digital European Cordless Telephone (DECT), PHS, PCS, Cellular, UHF and 800 MHz Special Mobile Radio (SMR), UHF Family Radio Services and 902 to 928 MHz cordless telephones. It features a mixer linearity control to preset or auto preset or auto program the mixer dynamic range, an enable function and buffered IF output for increased overall gain. Further details are covered in the Pin Function Description which shows the equivalent internal circuit and external circuit requirements.

### Current Regulation/Enable

Temperature compensating voltage independent current regulators are controlled by the the enable function in which "high" powers up the IC.

### Low Noise Amplifier (LNA)

The LNA is internally biased at low supply current (approximately 2.0 mA emitter current) for optimal noise figure and gain. Input and output matching may be achieved at various frequencies using few external components (see Application Circuit). Matching the LNA for maximum stable gain (MSG) yields noise performance within a few tenths of a dB of the minimum noise figure. Typical performance at 1.0 GHz is 17 dB gain and 1.8 dB noise figure for Vcc at 3.0 to 5.0 Vdc.

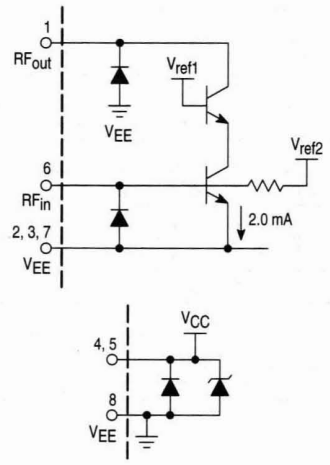
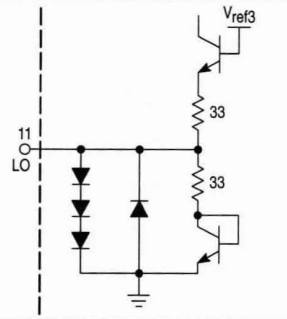
### Mixer

The mixer is a double–balanced four quadrant multiplier biased class AB allowing for programmable linearity control via an external current source. An input third order intercept point of 20 dBm may be achieved. All 3 ports of the mixer are designed to work up to 1.8 GHz. The mixer has a 50 Ω single–ended RF input and IF output buffer amplifier. The linear gain of the mixer is approximately 7.0 dB with a SSB noise figure of 16 dB.

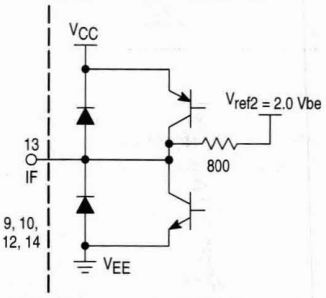
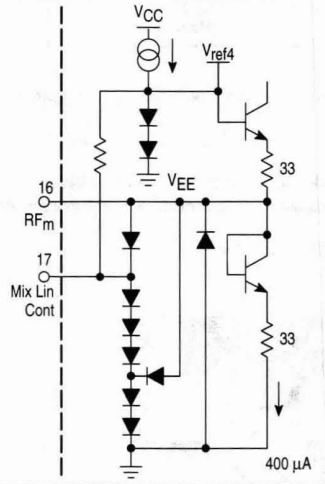
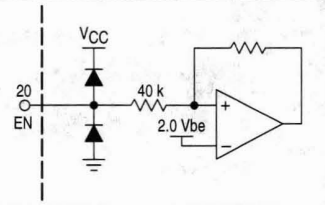
### Local Oscillator

It requires an external local oscillator source at –10 dBm input level to maximize the mixer gain.

## PIN FUNCTION DESCRIPTION

| 14 Pin SOIC | 20 Pin TQFP | Symbol | Equivalent Internal Circuit (20 Pin TQFP) | Functional Description/External Circuit Requirements |
|---|---|---|---|---|
| 4 | 6 | $RF_{in}$ |  | **RF Input**<br>The input is the base of an NPN low noise amplifier. Minimum external matching is required to optimize the input return loss and gain. |
| 2, 3 | 4, 5 | $V_{CC}$ | | **$V_{CC}$ – Positive Supply Voltage**<br>Two $V_{CC}$ pins are provided for the Local Oscillator and LO Buffer Amplifier. The operating supply voltage range is from 2.7 Vdc to 6.5 Vdc. In the PCB layout, the $V_{CC}$ trace must be kept as wide as feasible to minimize inductive reactances along the trace. $V_{CC}$ should be decoupled to $V_{EE}$ at the IC pin as shown in the component placement view. |
| 1, 5 | 2, 3, 7 and 8 | $V_{EE}$ | | **$V_{EE}$ – Negative Supply**<br>$V_{EE}$ pin is taken to an ample dc ground plane through a low impedance path. The path should be kept as short as possible. A two sided PCB is implemented so that ground returns can be easily made through via holes. |
| 14 | 1 | $RF_{out}$ | | **RF Output**<br>The output is from the collector of the LNA. As shown in the 926 MHz application receiver the output is conjugately matched with a shunt L, and series L and C network. |
| 7 | 11 | LO |  | **Local Oscillator Input**<br>50 Ω single–ended buffered LO input. |

**PIN FUNCTION DESCRIPTION (continued)**

| 14 Pin SOIC | 20 Pin TQFP | Symbol | Equivalent Internal Circuit (20 Pin TQFP) | Functional Description/External Circuit Requirements |
|---|---|---|---|---|
| 5, 6 | 9, 10, 12, 14 | $V_{EE}$ |  | **$V_{EE}$ – Negative Supply**<br>These pins are $V_{EE}$ supply for the IF and LO. In the application PC board these pins are tied to a common $V_{EE}$ trace with other $V_{EE}$ pins. |
| 8 | 13 | IF | | **IF Output**<br>The IF is a 800 Ω single–ended output which must be externally matched to 50 Ω for optimal performance. |
| 10 | 16 | $RF_m$ |  | **Mixer RF Input**<br>The mixer input impedance is broadband 50 Ω for applications up to 1.8 GHz. It easily interfaces with a RF ceramic filter as shown in the application schematic. The pin dc bias is set at 1.0 Vbe. |
| 11 | 17 | Mix Lin Cont | | **Mixer Linearity Control**<br>The mixer linearity control circuit accepts approximately 0 to 2.3 mA control current to set the dynamic range of the mixer. An Input Third Order Intercept Point, IIP3 of 20 dBm may be achieved at 2.3 mA of control current (approximately 7.0 mA of additional supply current). The pin dc bias is set at 2.0 Vbe. |
| 12 | 18, 19 | $V_{EE}$ | | **$V_{EE}$ – Negative Supply**<br>These pins are $V_{EE}$ supply for the mixer input. |
| 13 | 20 | EN |  | **Enable**<br>The device is enabled by pulling up to $V_{CC}$ or greater than 2.0 Vbe. |

## APPLICATIONS INFORMATION

### Evaluation PC Board

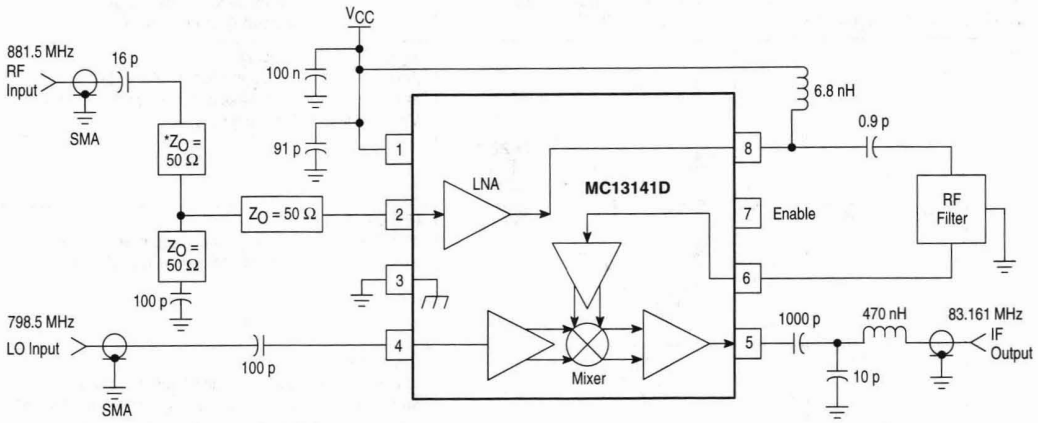
The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The PC board accommodates all SMT components on the circuit side (see Circuit Side Component Placement View). This evaluation board will be discussed and referenced in this section.

### Component Selection

The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers and coil types. The circuit side placement view is illustrated for the components specified in the application circuit. The application circuit schematic specifies particular components that were used to achieve the results given and specified in the tables but alternate components of the same Q and value should give similar results.

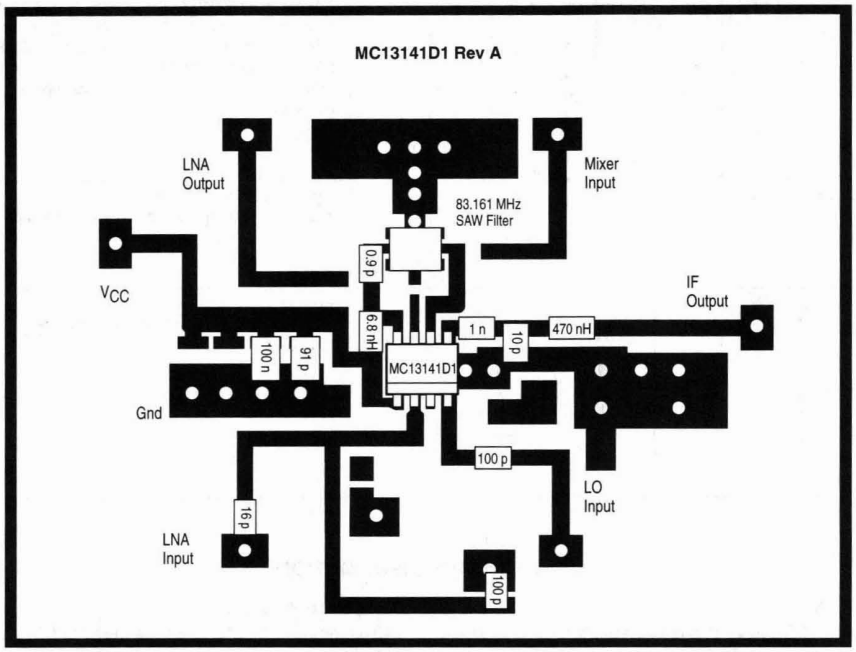
8

**Figure 1. MC13141D1 Application Circuit (881.5 MHZ)**




**NOTE:** *50 Ω Microstrip Transmission Line; length shown in Figure 2.

**Figure 2. Circuit Side Component Placement View**

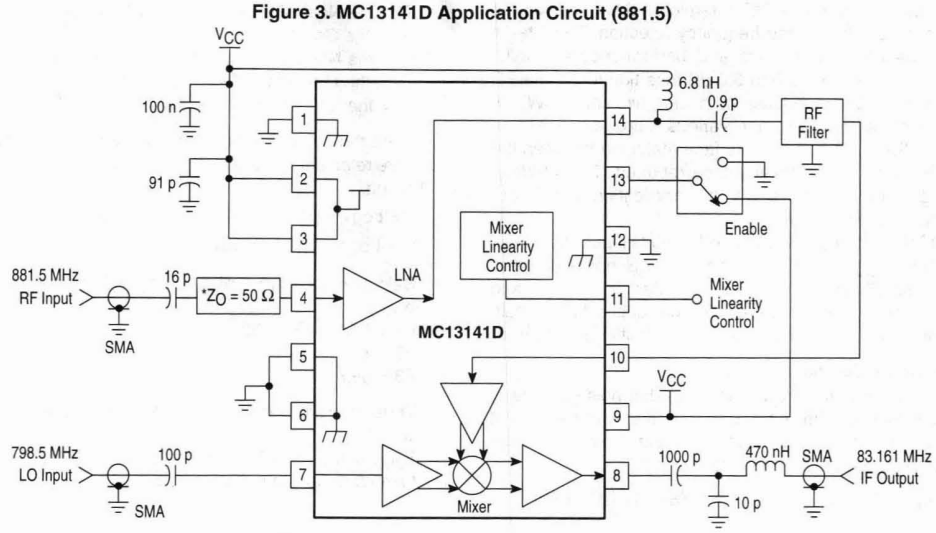



**NOTES:** 881.5 MHz SAW filter in the ceramic surface mount package is available from several sources: Siemens part # B39881–B4608–Z010 is an example. Other suppliers include Toko and Murata.

The PCB accommodates ceramic dielectric filters for applications in Cellular, DECT, PHS and ISM bands at 902–928 and 2.4–2.5 GHz. Toko makes a full line–up covering the above bands.

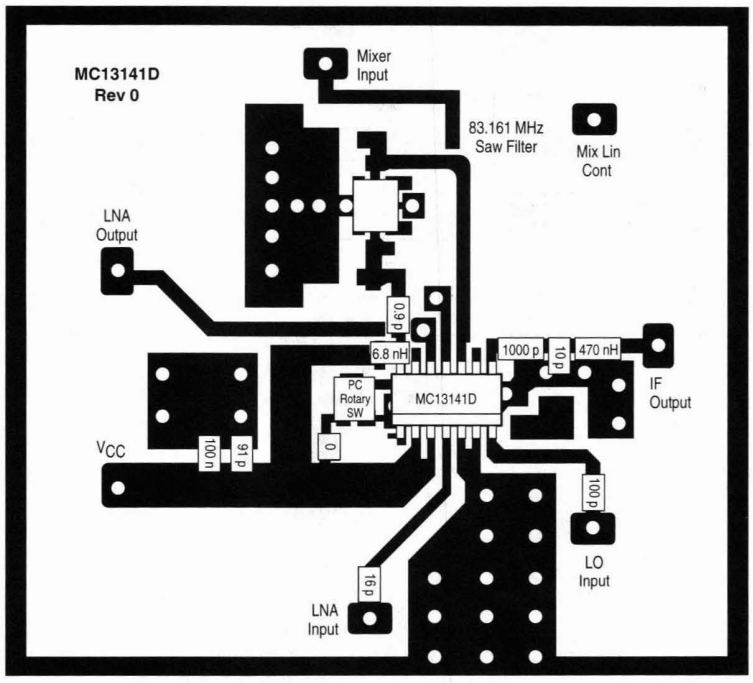
The PCB may be used without an image filter; ac couple the LNA to the mixer. Traces are provided on the PCB to evaluate the LNA and mixer separately. The component placement view shows external circuit components used in the 881.5 MHz application circuit. It is necessary to cut a section in the trace before placing the 0.9 pF capacitor. Capacitors should be 0805 size; the 6.8 nH inductor is a Toko type LL2012.

**Figure 3. MC13141D Application Circuit (881.5)**




**NOTE:** *50 Ω Microstrip Transmission Line; length shown in Figure 4.

**Figure 4. Circuit Side Component Placement View**




**NOTES:** 881.5 MHz SAW filter in the ceramic surface mount package is available from several sources: Siemens part # B39881–B4608–Z010 is an example. Other suppliers include Toko and Murata.

The PCB accommodates ceramic dielectric filters for applications in Cellular, DECT, PHS and ISM bands at 902–928 and 2.4–2.5 GHz. Toko makes a full line–up covering the above bands.

The PCB may be used without an image filter; ac couple the LNA to the mixer. Traces are provided on the PCB to evaluate the LNA and mixer separately. The component placement view shows external circuit components used in the 881.5 MHz application circuit. It is necessary to cut a section in the trace before placing the 0.9 pF capacitor. Capacitors should be 0805 size; the 6.8 nH inductor is a Toko type LL2012.

**Input Matching/Components**

It is desirable to use a RF ceramic or SAW filter before the mixer to provide image frequency rejection. The filter is selected based on cost, size and performance tradeoffs. Typical RF filters have 3.0 to 5.0 dB insertion loss. The PC board layout accommodates both ceramic and SAW RF filters which are offered by various suppliers such as Siemens, Toko and Murata. Interface matching between the LNA, RF filter and the mixer will be required. The interface matching networks shown in the application circuit are designed for 50 Ω interfaces.

The LNA is conjugately matched to 50 Ω input and output at 3.0 Vdc $V_{CC}$. 17 dB gain and 1.8 dB noise figure is typical at 881.5 MHz. The mixer measures 7.0 dB gain and 16 dB noise figure as shown in the application circuit. Typical insertion loss of the Siemens SAW filter is 3.0 dB.

**System Noise Considerations**

The block diagram shows the cascaded noise stages of the MC13141 in the front–end receiver subsystem; it represents the application circuit. In the cascaded noise analysis the system noise equation is:

$$F_{system} = F1 + [(F2 - 1)/G1] + [(F3 - 1)] / [(G1)(G2)]$$

where:

F1 = the Noise Factor of the MC13142 LNA
G1 = the Gain of the LNA
F2 = the Noise factor of the RF Ceramic Filter
G2 = the Gain of the Ceramic Filter
F3 = the Noise factor of the Mixer

Note: the above terms are defined as linear relationships and are related to the log form for gain and noise figure by the following:

$F = \text{Log}^{-1}[(\text{NF in dB})/10]$ and similarly

$G = \text{Log}^{-1}[(\text{Gain in dB})/10]$

Calculating in terms of gain and noise factor yields the following:

F1 = 1.51 ; G1 = 50.11
F2 = 1.99 ; G2 = 0.5
F3 = 39.8

Thus, substituting in the equation for subsystem noise factor:

$F_{subsystem} = 3.08$ ; $NF_{subsystem} = 4.9$ dB
Overall Subsystem Gain = 21 dB

**Figure 5. Front–End Subsystem Block Diagram for Noise Analysis**

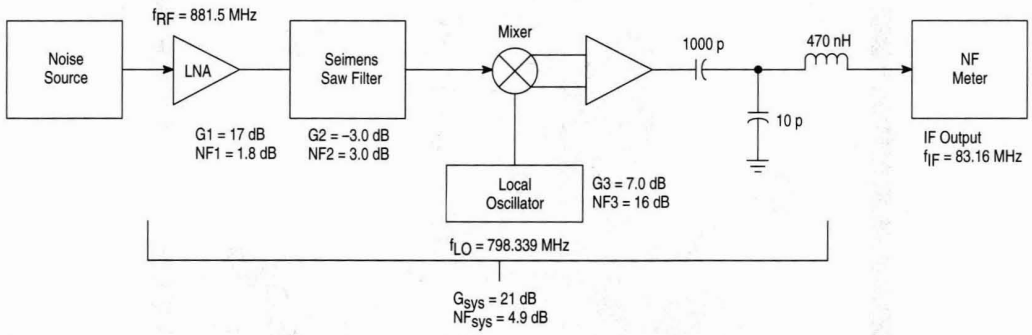
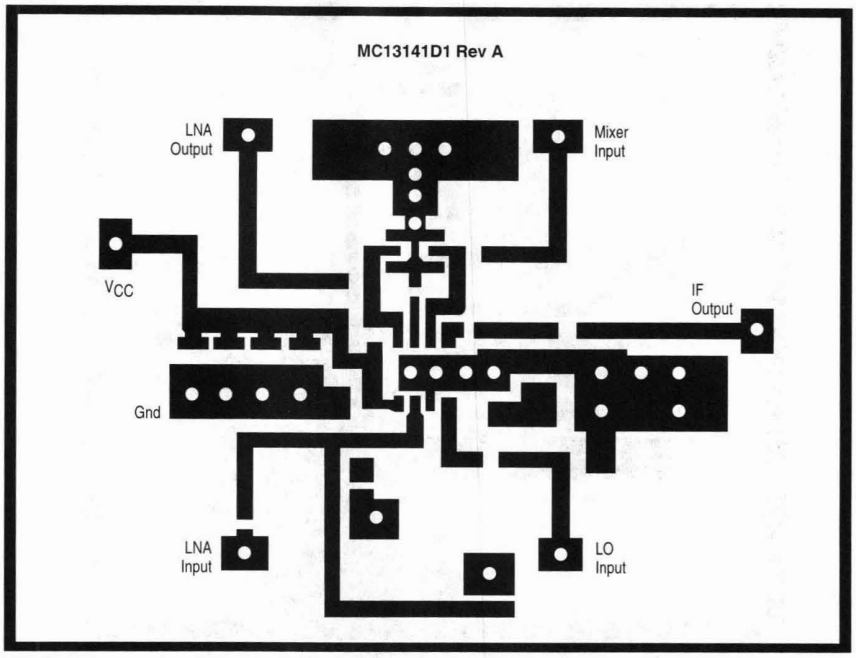


**Figure 6. Circuit Side View**




**NOTES:** Critical dimensions are 50 mil centers lead to lead in SO–8 footprint.
Also line widths to labeled ports excluding $V_{CC}$ are 50 mil (0.050 inch).
FR4 PCB, 1/32 inch.

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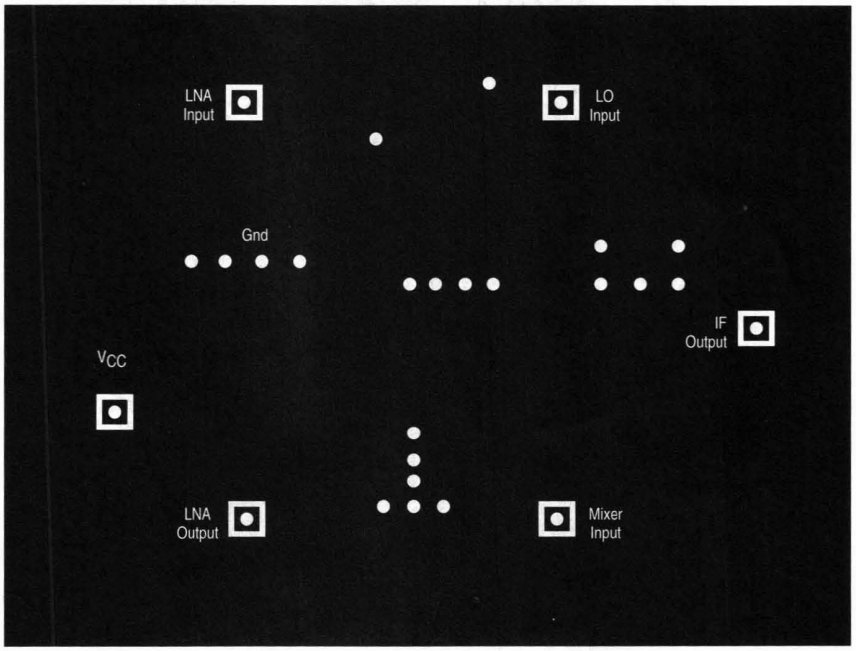
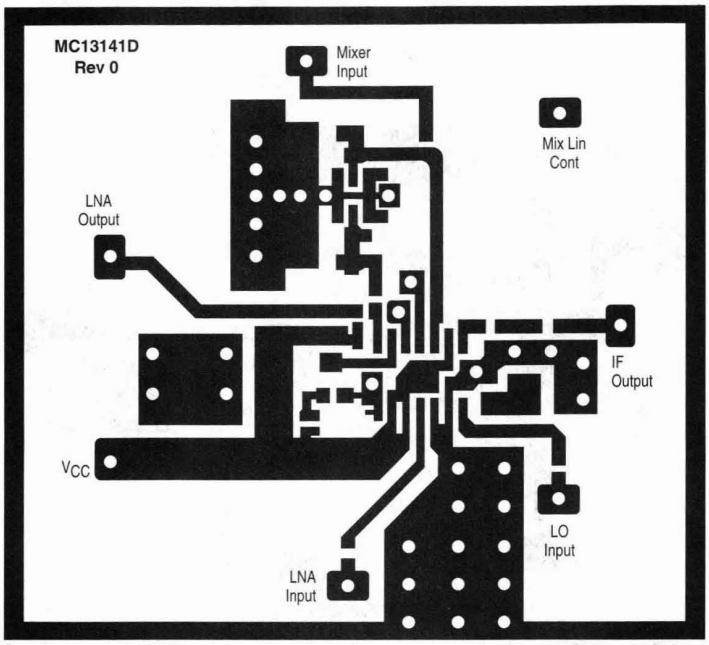
**Figure 7. MC13141D1 Rev A – Ground Side View**




**NOTE:** FR4 PCB, 1/32 inch.

**Figure 8. Circuit Side View**




**NOTES:** Critical dimensions are 50 mil centers lead to lead in SO–14 footprint.
Also line widths to labeled ports excluding $V_{CC}$ are 50 mil (0.050 inch).
FR4 PCB, 1/32 inch.

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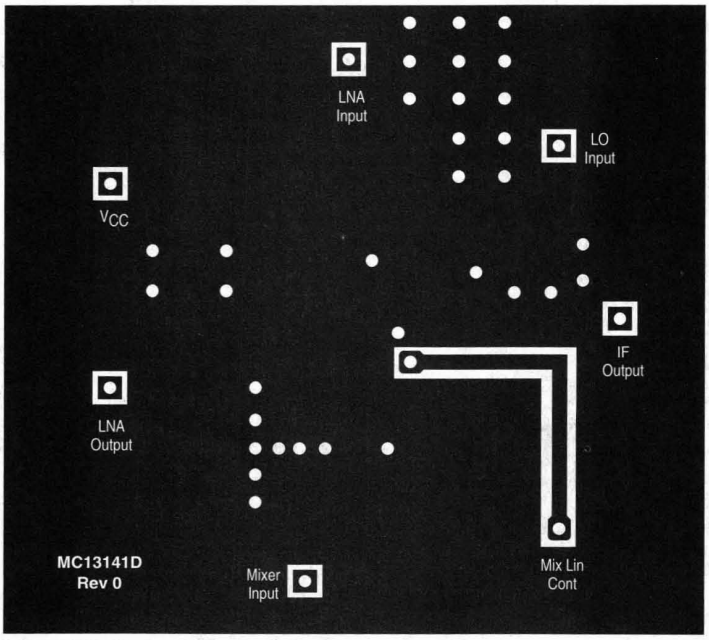
**Figure 9. Ground Side View**




**NOTE:** FR4 PCB, 1/32 inch.

MOTOROLA

# MC13142

*Product Preview*

## Low Power DC - 1.8 GHz LNA, Mixer and VCO

**LOW POWER DC – 1.8 GHz LNA, MIXER and VCO**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13142 is intended to be used as a first amplifier, voltage controlled oscillator and down converter for RF applications. It features wide band operation, low noise, high gain and high linearity while maintaining low current consumption. The circuit consists of a Low Noise Amplifier (LNA), a Voltage Controlled Oscillator (VCO), a buffered oscillator output, a mixer, an Intermediate Frequency amplifier ($IF_{amp}$) and a dc control section. The wide mixer IF bandwidth allows this part also to be used as an up converter and exciter amplifier.

- Wide RF Bandwidth: DC–1.8 GHz
- Wide LO Bandwidth: DC–1.8 GHz
- Wide IF Bandwidth: DC–1.8 GHz
- Low Power: 13 mA @ $V_{CC}$ = 2.7–6.5 V
- High Mixer Linearity: $P_{i1.0\ dB}$ = +3.0 dBm
- Linearity Adjustment Increases $IP_{3in}$ Up to +20 dBm
- Single–Ended 50 Ω Mixer Input
- Double Balanced Mixer Operation
- Open Collector Mixer Output
- Single Transistor Oscillator with Collector, Base and Emitter Pinned Out
- Buffered Oscillator Output
- Mixer and Oscillator Can be Enabled Independently in TQFP–20 Package Only

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

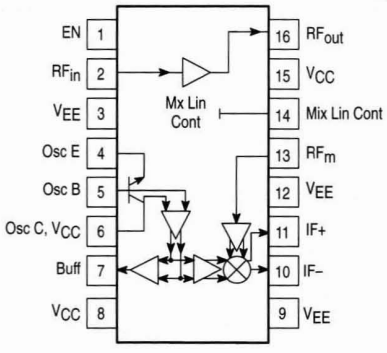
**FTB SUFFIX**
PLASTIC PACKAGE
CASE 976
(Thin QFP)

**ORDERING INFORMATION**

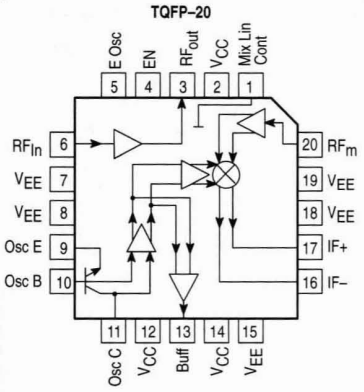
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13142D | $T_A$ = –40° to +85°C | SO–16 |
| MC13142FTB | | TQFP–20 |

**PIN CONNECTIONS**

SO–16




TQFP–20




This device contains 176 active transistors.

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 (max) | Vdc |
| Operating Supply Voltage Range | $V_{CC}$ | 2.7–6.5 | Vdc |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 3.0 V, $T_A$ = 25°C, $LO_{in}$ = –10 dBm @ 950 MHz, IF @ 50 MHz.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current (Power Down) | $I_{CC}$ | – | 100 | – | pA |
| Supply Current (Power Up) | $I_{CC}$ | – | 13.5 | – | mA |
| Amplifier Gain (50 Ω Insertion Gain) | $S_{21}$ | – | 12 | – | dB |
| Amplifier Reverse Isolation | $S_{12}$ | – | –33 | – | dB |
| Amplifier Input Match | $\Gamma_{in\ amp}$ | – | –10 | – | dB |
| Amplifier Output Match | $\Gamma_{out\ amp}$ | – | –15 | – | dB |
| Amplifier 1.0 dB Gain Compression | $Pin_{-1.0\ dB}$ | – | –15 | – | dBm |
| Amplifier Input Third Order Intercept | $IP3_{in}$ | – | –5.0 | – | dBm |
| Amplifier Noise Figure (Application Circuit) | NF | – | 1.8 | – | dB |
| Amplifier Gain @ N.F. | $G_{NF}$ | – | 17 | – | dB |
| Mixer Voltage Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $VG_C$ | – | 9.0 | – | dB |
| Mixer Power Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $PG_C$ | – | –3.0 | – | dB |
| Mixer Input Match | $\Gamma_{in\ M}$ | – | –20 | – | dB |
| Mixer SSB Noise Figure | $NF_{SSBM}$ | – | 12 | – | dB |
| Mixer 1.0 dB Gain Compression | $Pin_{-1.0\ dBM}$ | – | 3.0 | – | dBm |
| Mixer Input Third Order Intercept | $IP3_{InM}$ | – | –1.0 | – | dBm |
| Oscillator Buffer Drive (50 Ω) | $P_{VCO}$ | – | –16 | – | dBm |
| Oscillator Phase Noise @ 25 kHz Offset | $N_\Phi$ | – | –90 | – | dBc/Hz |
| $RF_{in}$ Feedthrough to $RF_m$ | $P_{RFin–RFm}$ | – | –35 | – | dB |
| $RF_{out}$ Feedthrough to $RF_m$ | $P_{RFout–RFm}$ | – | –35 | – | dB |
| LO Feedthrough to IF | $P_{LO–IF}$ | – | –35 | – | dBm |
| LO Feedthrough to $RF_{in}$ | $P_{LO–RFin}$ | – | –35 | – | dBm |
| LO Feedthrough to $RF_m$ | $P_{LO–RFm}$ | – | –35 | – | dBm |
| Mixer RF Feedthrough to IF | $P_{RFm–IF}$ | – | –25 | – | dB |
| Mixer RF Feedthrough to $RF_{in}$ | $P_{RFm–RFin}$ | – | –25 | – | dB |

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## CIRCUIT DESCRIPTION

### General

The MC13142 is a low power LNA, double–balanced Mixer, and VCO. This device is designated for use as the frontend section in analog and digital FM systems such as Digital European Cordless Telephone (DECT), PHS, PCS, Cellular, UHF and 800 MHz Special Mobile Radio (SMR), UHF Family Radio Services and 902 to 928 MHz cordless telephones. It features a mixer linearity control to preset or auto program the mixer dynamic range, an enable function and a wideband IF so the IC may be used either as a down converter or an up converter. Further details are covered in the Pin by Pin Description which shows the equivalent internal circuit and external circuit requirements.

### Current Regulation/Enable

Temperature compensating voltage independent current regulators are controlled by the enable function in which "high" powers up the IC.

### Low Noise Amplifier (LNA)

The LNA is internally biased at low supply current (approximately 2.0 mA emitter current) for optimal noise figure and gain. The LNA output is biased internally with a 600 Ω resistor to $V_{CC}$. Input and output matching may be achieved at various frequencies using few external components. Matching the LNA for Maximum stable gain (MSG) yields noise performance within a few tenths of a dB of the minimum noise figure.

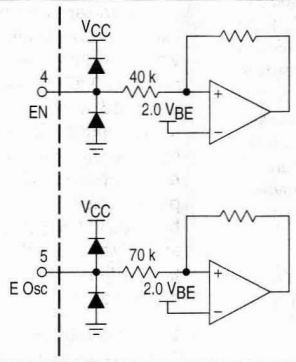
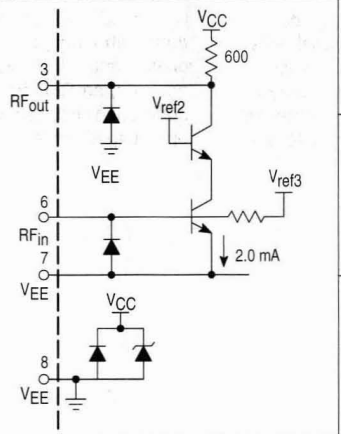
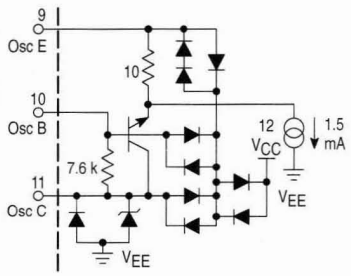
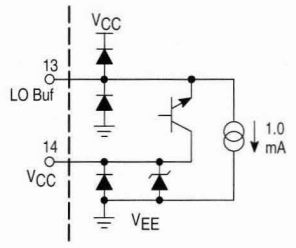
### Mixer

The mixer is a double–balanced four quadrant multiplier biased class AB allowing for programmable linearity control via an external current source. An input third order intercept point of 20 dBm may be achieved. All 3 ports of the mixer are designed to work up to 1.8 GHz. The mixer has a 50 Ω single–ended RF input and open collector differential IF outputs. An on–board Local Oscillator transistor has the emitter, base and collector pinned out to implement a low phase noise VCO in various configurations. Additionally, a buffered LO output is provided for operation with a frequency synthesizer. The linear gain of the mixer is approximately 0 dB with a SSB noise figure of 12 dB in the IF output circuit configuration shown in the application example.

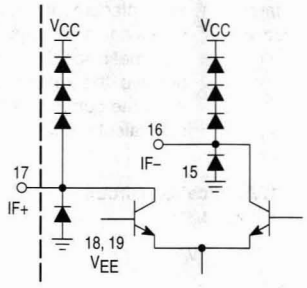
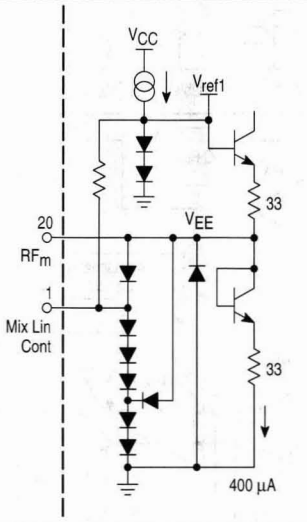
### Local Oscillator

The on–chip transistor operates with coaxial transmission line or LC resonant elements to over 2.0 GHz. Biasing is done with a temperature compensated current source in the emitter and a collector to base internal resistor of 7.6 kΩ; however, an RFC from $V_{CC}$ to base is recommended. The application circuit shows a voltage controlled Clapp oscillator operating at center frequency of 975 MHz.

## PIN FUNCTION DESCRIPTION

| Pin | | Symbol | Equivalent Internal Circuit (20 Pin TQFP) | Description |
|---|---|---|---|---|
| 16 Pin SOIC | 20 Pin TQFP | | | |
| 1 | 4 | EN |  | **Enable, E Osc**<br>In SO–16, both enables, (for the Oscillator/LO Buffer and LNA/Mixer) are bonded to Pin 1. In the TQFP, two pins are provided, Pin 5, E Osc enables the oscillator and buffer while Pin 4, EN enables the LNA/Mixer.<br>Enable by pulling up to $V_{CC}$ or to greater than 2.0 $V_{BE}$. |
| | 5 | E Osc | | |
| 2 | 6 | $RF_{in}$ |  | **RF Input**<br>The input is the base of an NPN low noise amplifier. Minimum external matching is required to optimize the input return loss and gain. |
| 3 | 7, 8 | $V_{EE}$ | | **$V_{EE}$ – Negative Supply**<br>$V_{EE}$ pin is taken to an ample dc ground plane through a low impedance path. The path should be kept as short as possible. A two sided PCB is implemented so that ground returns can be easily made through via holes. |
| 16 | 3 | $RF_{out}$ | | **RF Output**<br>The output is from the collector of the LNA; it is internally biased with a 600 Ω resistor to $V_{CC}$. As shown in the 926 MHz application receiver the output is conjugately matched with a shunt L, and series L and C network. |
| 4<br>5<br>6 | 9<br>10<br>11 | Osc E<br>Osc B<br>Osc C |  | **On–Board VCO Transistor**<br>The transistor has the emitter, base and collector + $V_{CC}$ pins available. Internal biasing which is compensated for stability over temperature is provided. It is recommended that the base pin is pulled up to $V_{CC}$ through an RFC chosen for the particular oscillator center frequency. The application circuit shows a modified Colpitts or Clapp oscillator configuration and its design is discussed in detail in the application section. |
| 6<br>8 | 12<br>14 | $V_{CC}$<br>$V_{CC}$ | | **Supply Voltage ($V_{CC}$)**<br>Two $V_{CC}$ pins are provided for the Local Oscillator and LO Buffer Amplifier. The operating supply voltage range is from 2.7 Vdc to 6.5 Vdc. In the PCB layout, the $V_{CC}$ trace must be kept as wide as feasible to minimize inductive reactances along the trace. $V_{CC}$ should be decoupled to $V_{EE}$ at the IC pin as shown in the component placement view. |
| 7 | 13 | LO Buff |  | **Local Oscillator Buffer**<br>This is a buffered output providing –16 dBm (50 Ω termination) to drive the $f_{in}$ pin of a PLL synthesizer. Impedance matching to the synthesizer may be necessary to deliver the optimal signal and to improve the phase noise performance of the VCO. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | | Symbol | Equivalent Internal Circuit (20 Pin TQFP) | Description |
|---|---|---|---|---|
| 16 Pin SOIC | 20 Pin TQFP | | | |
| 9, 12 | 15, 18, 19 | $V_{EE}$ |  | **$V_{EE}$, Negative Supply**<br>These pins are $V_{EE}$ supply for the mixer IF output. In the application PC board these pins are tied to a common $V_{EE}$ trace with other $V_{EE}$ pins. |
| 10, 11 | 16, 17 | IF–, IF+ | | **IF Output**<br>The IF is a differential open collector configuration which designed to use over a wide frequency range for up conversion as well as down conversion. Differential to single–ended circuit configuration and matching options are discussed in the application section. 6.0 dB of additional Mixer gain can be achieved by conjugately matching at the desired IF frequency. |
| 13 | 20 | $RF_m$ |  | **Mixer RF Input**<br>The mixer input impedance is broadband 50 Ω for applications up to 1.8 GHz. It easily interfaces with a RF ceramic filter as shown in the application schematic. |
| 14 | 1 | Mix Lin Cont | | **Mixer Linearity Control**<br>The mixer linearity control circuit accepts approximately 0 to 2.3 mA control current to set the dynamic range of the mixer. An Input Third Order Intercept Point, IIP3 of 20 dBm may be achieved at 2.3 mA of control current (approximately 7.0 mA of additional supply current). |

8

## APPLICATIONS INFORMATION

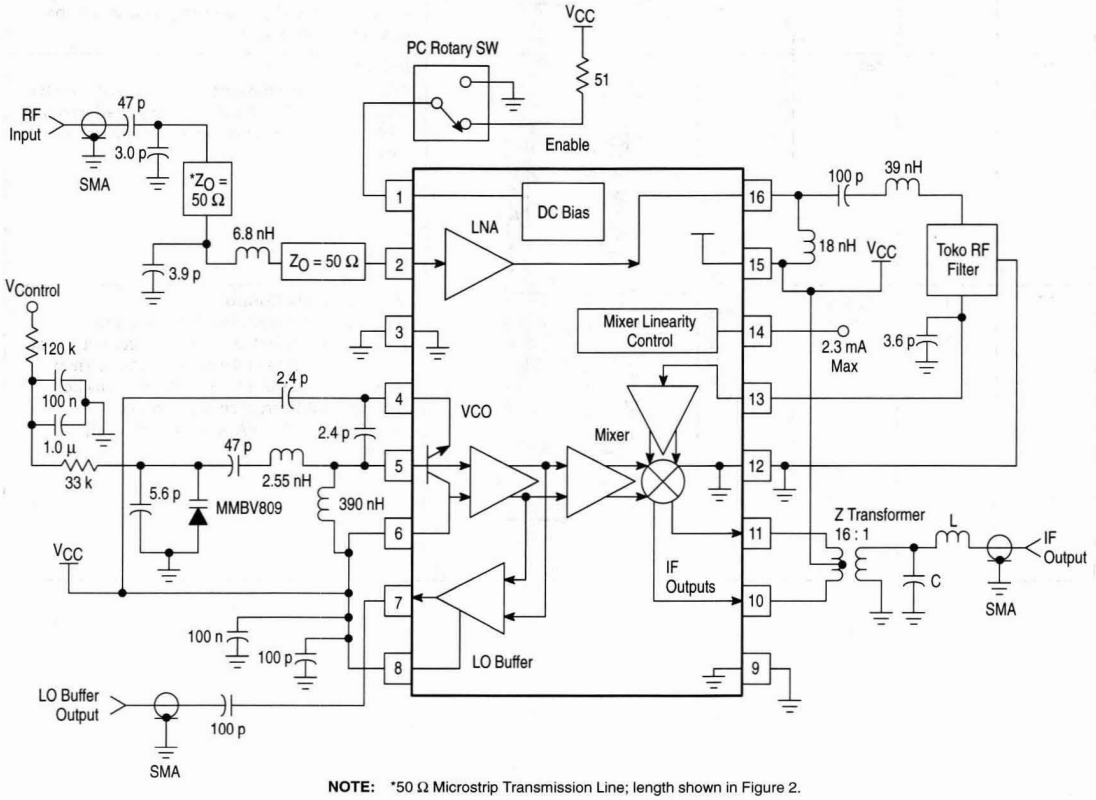
### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The PC board accommodates all SMT components on the circuit side (see Circuit Side Component Placement View). This evaluation board will be discussed and referenced in this section.

### Component Selection

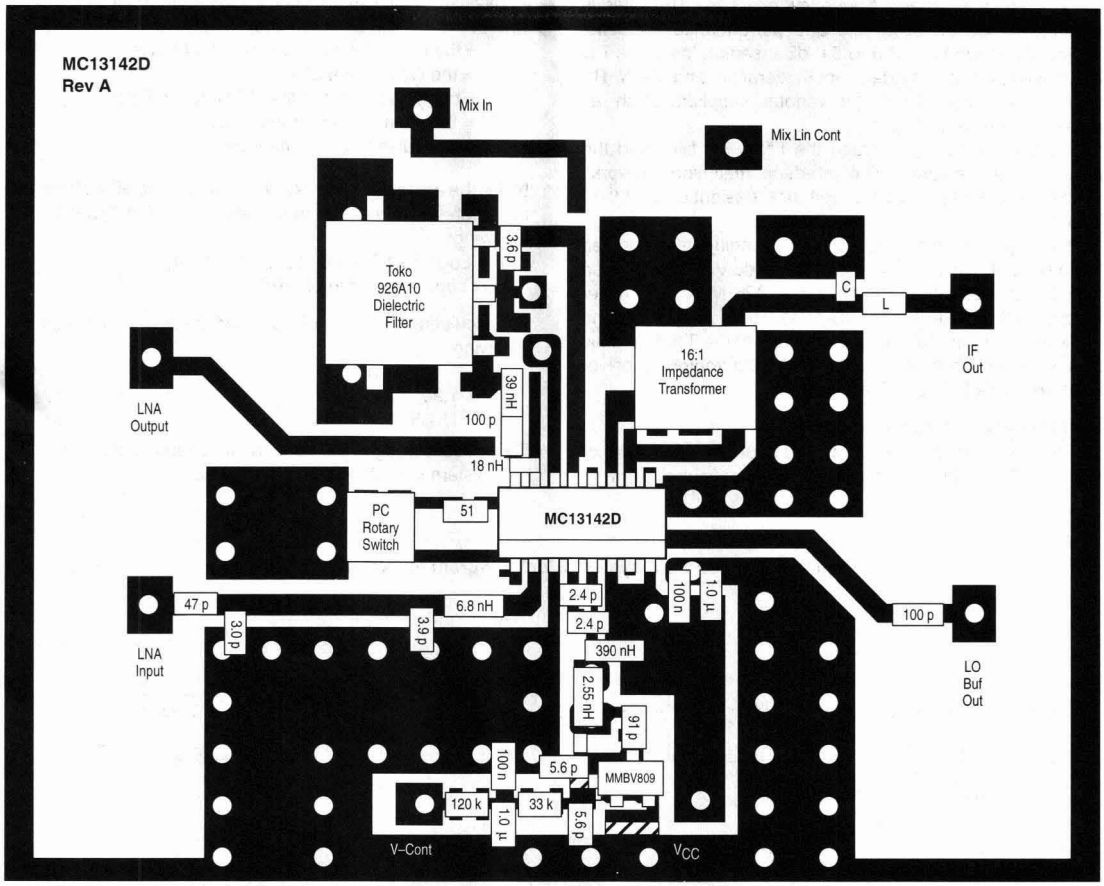
The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers. The circuit side placement view is illustrated for the components specified in the application circuit. The application circuit schematic specifies particular components that were used to achieve the results given and specified in the tables but alternate components of the same Q and value should give equivalent results.

**Figure 1. Application Circuit**
(926.5 MHz)




**NOTE:** *50 Ω Microstrip Transmission Line; length shown in Figure 2.

**Figure 2. Circuit Side Component Placement View**




**NOTES:** The PCB is laidout for the 4DFA (2 pole SMD type) and 4DFB (3 pole SMD type) filters which are available for applications in cellular and GSM,GPS (1.2–1.5 GHz), DECT, PHS and PCS (1.8–2.0 GHz) and ISM Bands (902–928 MHz and 2.4–2.5 GHz). In the component placement shown above, the 926.5 MHz dielectric type image filter is used (Toko Part # 4DFA–926A10).

The PCB also accommodates a surface mount SAW filter in an eight or six pin ceramic package for the cellular base and handset frequencies. Recommended manufacturers are Siemens and Murata.

Traces are provided on the PCB to evaluate the LNA and mixer separately. The component placement view shows external circuit components used for the 926.5 MHz application circuit. Note: some traces must be cut to accommodate placement of components; likewise some traces must be shorted. The voltage controlled oscillator is shown with the varactor referenced to $V_{EE}$ ground. The PCB is modified as shown to do this.

16:1 broadband impedance transformer is mini circuits part #TX16–R3T; it is in the leadless surface mount "TX" package. Components L and C comprise a low pass filter used to provide narrowband matching at a given IF frequency. For example at 49 MHz C = 36 p and L = 330 nH.
The microstrip trace on the ground side of the PCB is intended for a microstrip resonator; it is cut free when using a lump inductor as done above.

8

**Input Matching/Components**

It is desirable to use a RF ceramic or SAW filter before the mixer to provide image frequency rejection. The filter is selected based on cost, size and performance tradeoffs. Typical RF filters have 3.0 to 5.0 dB insertion loss. The PC board layout accommodates both ceramic and SAW RF filters which are offered by various suppliers such as Siemens, Toko and Murata.

Interface matching between the LNA, RF filter and the mixer will be required. The interface matching networks shown in the application circuit are designed for 50 Ω interfaces.

In the application circuit, the LNA is conjugately matched to 50 Ω input and output for 3.0 to 5.0 Vdc $V_{CC}$. 17 dB gain and 1.8 dB noise figure is typical at 926 MHz. The mixer measures 0 dB gain and 12 dB noise figure as shown in the application circuit. Typical insertion loss of the Toko ceramic filter is 3.0 dB. Thus, the overall gain of the frontend receiver is 14 dB with a 3.3 dB noise figure.

**System Noise Considerations**

The block diagram shows the cascaded noise stages of the MC13142 in the frontend receiver subsystem; it represents the application circuit. In the cascaded noise analysis the system noise equation is:

Fsystem = F1 + [(F2 –1)/G1] + [(F3–1)]/[(G1)(G2)]

where:

F1 = the Noise Factor of the MC13142 LNA
G1 = the Gain of the LNA
F2 = the Noise factor of the RF Ceramic Filter
G2 = the Gain of the Ceramic Filter
F3 = the Noise factor of the Mixer

**Note**: the above terms are defined as linear relationships and are related to the log form for gain and noise figure by the following:

F = Log $^{-1}$ [(NF in dB)/10] and similarly
G = Log $^{-1}$ [(Gain in dB)/10].

Calculating in terms of gain and noise factor yields the following:

F1 = 1.51; G1 = 50.11
F2 = 1.99; G2 = 0.5
F3 = 15.85

Thus, substituting in the equation for system noise factor:

Fsystem = 2.12; NFsystem = 3.3 dB

**Figure 3. Frontend Subsystem Block Diagram for Noise Analysis**

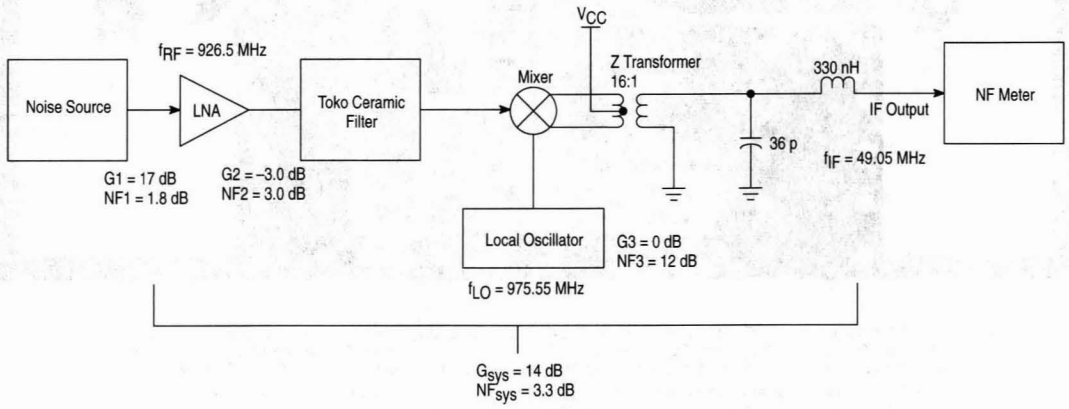



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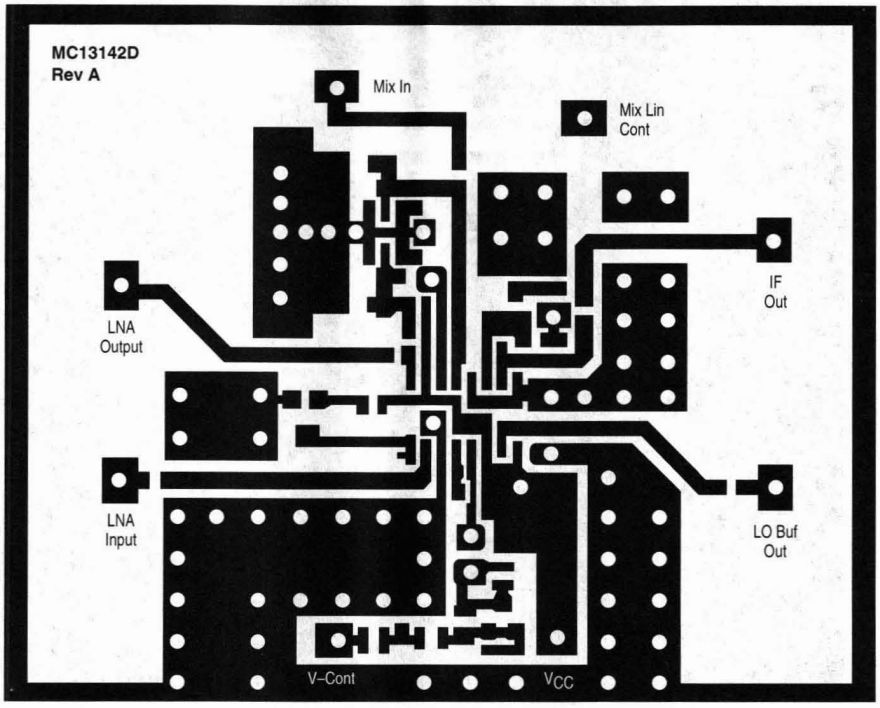
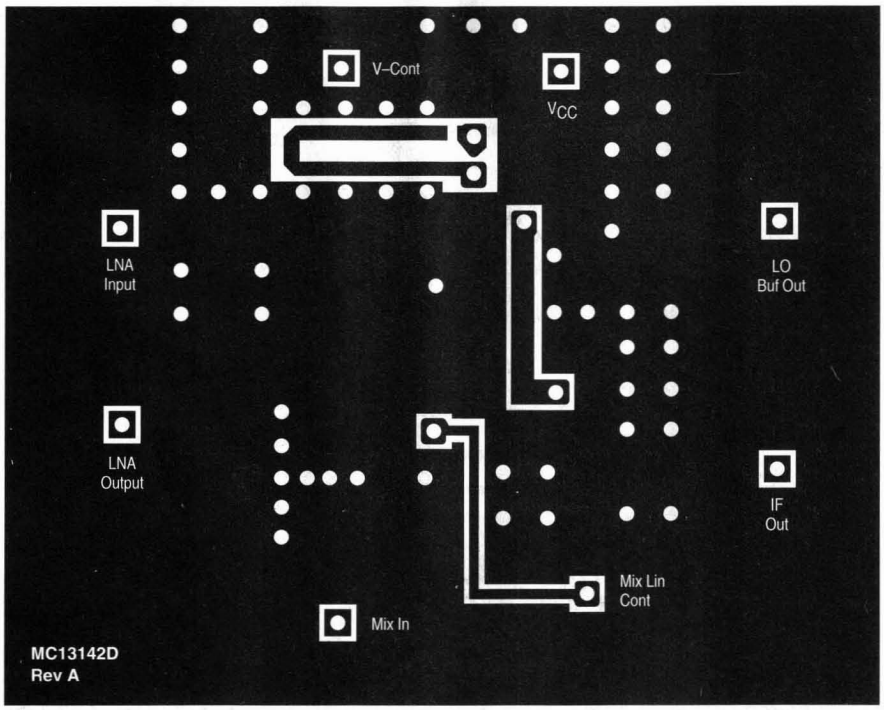
**Figure 4. Circuit Side View**




**NOTES:** Critical dimensions are 50 mil centers lead to lead in SO–16 footprint.
Also line widths to labeled ports excluding $V_{CC}$ are 50 mil (0.050 inch).
FR4 PCB, 1/32 inch.

8

Figure 5. Ground Side View




**NOTES**: FR4 PCB, 1/32 inch.

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MOTOROLA

# MC13143

*Product Preview*

## Ultra Low Power DC - 2.4 GHz Linear Mixer

The MC13143 is a high compression linear mixer with single–ended RF input, differential IF output and differential LO inputs which consumes as little as 1.8 mW. A new circuit topology is used to achieve a high third order intermodulation intercept point, high linearity and high 1.0 dB output compression point while maintaining a linear 50 Ω input impedance. It is designed for Up or Down conversion anywhere from dc to 2.4 GHz.

**Ultra Low Power: 1.0 mA @ $V_{CC}$ = 1.8–6.5 V**

- Wide Input Bandwidth: DC–2.4 GHz
- Wide Output Bandwidth: DC–2.4 GHz
- Wide LO Bandwidth: DC–2.4 GHz
- High Mixer Linearity: $P_{i1.0\ dB}$ = + 3.0 dBm

**Linearity Adjustment of up to $IP_{3in}$ = +20 dBm**

- 50 Ω Mixer Input
- Single–Ended Mixer Input
- Double Balanced Mixer Operation
- Differential Open Collector Mixer Output

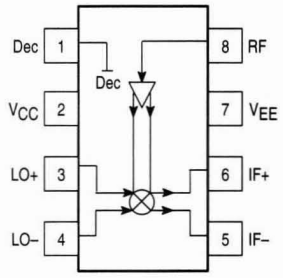
**ULTRA LOW POWER DC – 2.4 GHz LINEAR MIXER**

**SEMICONDUCTOR TECHNICAL DATA**

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

8

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13143D | $T_A$ = –40° to +85°C | SO–8 |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

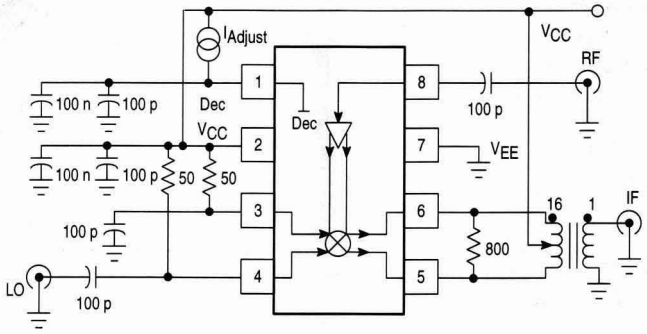
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 (max) | Vdc |
| Operating Supply Voltage Range | $V_{CC}$ | 1.8–6.5 | Vdc |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 2.0 V, $T_A$ = 25°C, RF = – 30 dBm @ 900 MHz, LO = 0 dBm @ 950 MHz, IF @ 50 MHz.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current | $I_{CC}$ | – | 1.0 | – | mA |
| Mixer Voltage Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $VG_C$ | – | 9.0 | – | dB |
| Mixer Power Conversion Gain ($R_P$ = $R_L$ = 800 Ω) | $PG_C$ | – | –5.0 | – | dB |
| Mixer Input Match | $\Gamma_{in}$ | – | –20 | – | dB |
| Mixer SSB Noise Figure | $NF_{SSB}$ | – | 12 | – | dB |
| Mixer 1.0 dB Gain Compression | $Pin_{-1.0\ dB}$ | – | 3.0 | – | dBm |
| Mixer Input Third Order Intercept | $IP3_{in}$ | – | –3.0 | – | dBm |
| LO Drive Level | $LO_{in}$ | – | –5.0 | – | dBm |
| LO Feedthrough to Mixer Out | $P_{LO-IF}$ | – | –25 | – | dB |
| Mixer Input Feedthrough Output | $P_{RFm-IF}$ | – | –25 | – | dB |
| Mixer Input Feedthrough to LO | $P_{RFm-LO}$ | – | –25 | – | dB |

**Figure 1. Test Circuit**




This device contains 29 active transistors.

## TYPICAL PERFORMANCE CURVES

**Figure 2. Power Conversion Gain and Supply Current versus Supply Voltage**

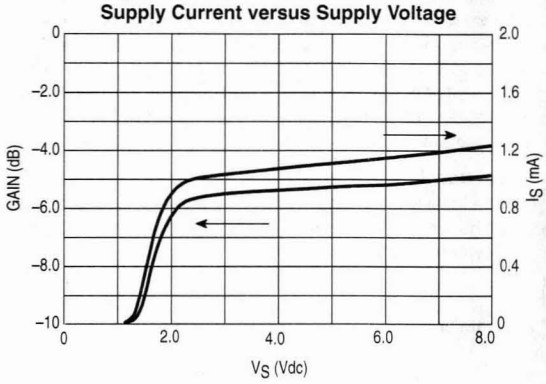



**Figure 3. Noise Figure and Gain versus LO Power**

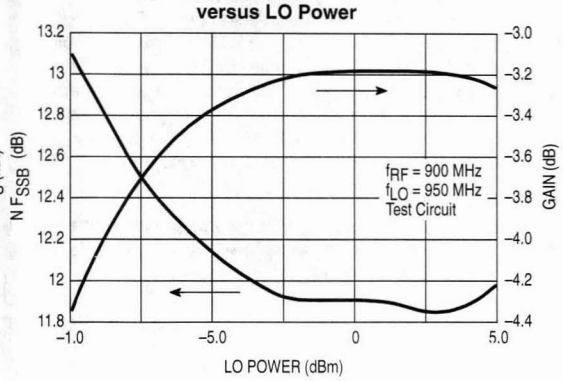



**Figure 4. Mixer Input Return Loss versus RF Input Frequency**

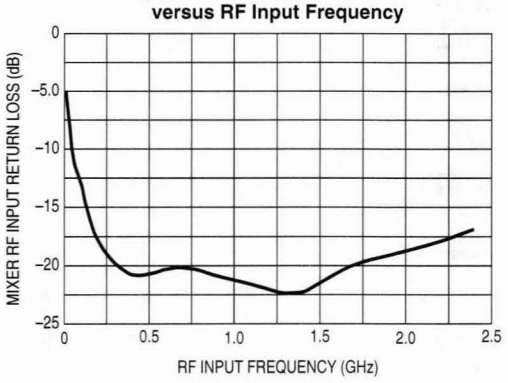



**Figure 5. Power Conversion Gain and Supply Current versus RF Input Power**

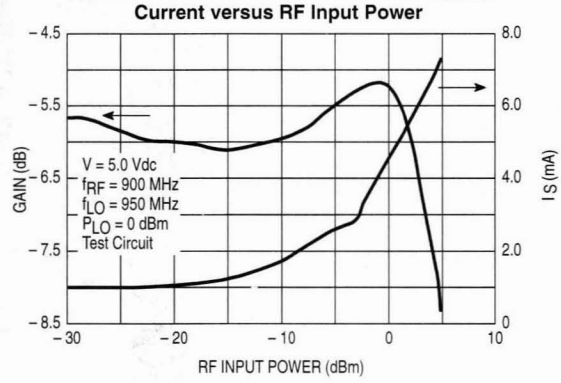



**Figure 6. Noise Figure and Gain versus RF Frequency**

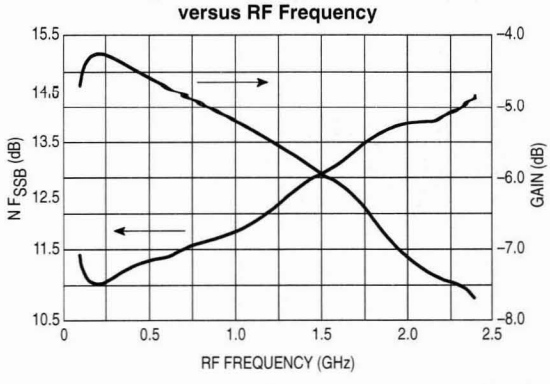
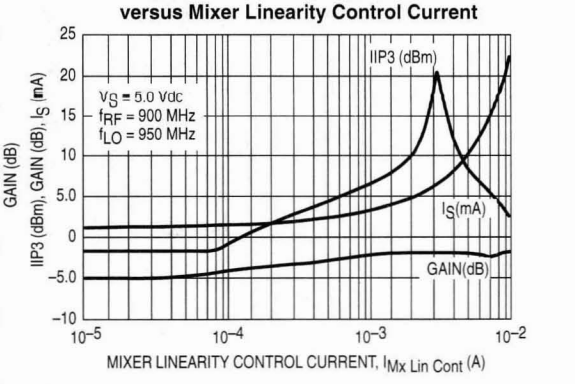



**Figure 7. IIP3, Gain, Supply Current versus Mixer Linearity Control Current**

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## CIRCUIT DESCRIPTION

### General

The MC13143 is a double–balanced Mixer. This device is designated for use as the frontend section in analog and digital FM systems such as Wireless Local Area Network (LAN), Digital European Cordless Telephone (DECT), PHS, PCS, GPS, Cellular, UHF and 800 MHz Special Mobile Radio (SMR), UHF Family Radio Services and 902 to 928 MHz cordless telephones. It features a mixer linearity control to preset or auto program the mixer dynamic range, an enable function and a wideband IF so the IC may be used either as a down converter or an up converter.

### Current Regulation

Temperature compensating voltage independent current regulators provide typical supply current at 1.0 mA with no mixer linearity control current.

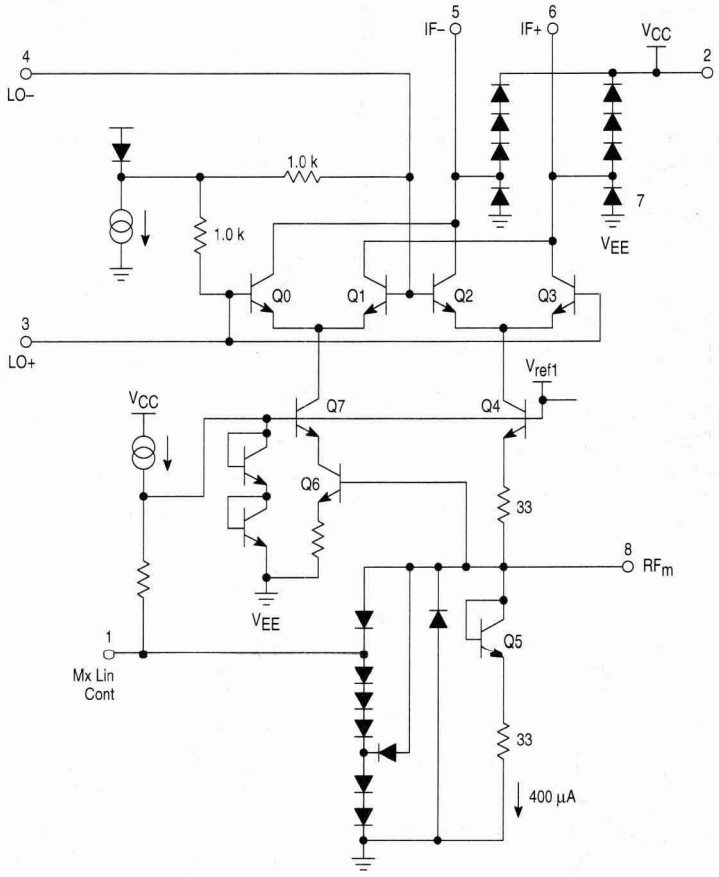
### Mixer

The mixer is a unique and patented double–balanced four quadrant multiplier biased class AB allowing for programmable linearity control via an external current source. An input third order intercept point of 20 dBm may be achieved. All 3 ports of the mixer are designed to work up to 2.4 GHz. The mixer has a 50 Ω single–ended RF input and open collector differential IF outputs (see Internal Circuit Schematic for details). The linear gain of the mixer is approximately –5.0 dB with a SSB noise figure of 12 dB.

### Local Oscillator

The local oscillator has differential input configuration that requires typically –10 dBm input from an external source to achieve the optimal mixer gain.

**Figure 8. MC13143 Internal Circuit***




**NOTE:** * The MC13143 uses a unique and patented circuit topology.

## APPLICATIONS INFORMATION

### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The PC board is laid out to accommodate all SMT components on the circuit side (see Circuit Side Component Placement View).

### Component Selection

The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers. The circuit side placement view is illustrated for the components specified in the application circuit. The Component Placement View specifies particular components that were used to achieve the results shown in the typical curves and tables.

### Mixer Input

The mixer input impedance is broadband 50 Ω for applications up to 2.4 GHz. It easily interfaces with a RF ceramic filter as shown in the application schematic.

### Mixer Linearity Control

The mixer linearity control circuit accepts approximately 0 to 2.3 mA control current. An Input Third Order Intercept Point, IIP3 of 20 dBm may be achieved at 2.3 mA of control current (approximately 7.0 mA of additional supply current).

### Local Oscillator Inputs

The differential LO inputs are internally biased at $V_{CC} - 1.0\ V_{BE}$; this is suitable for high voltage and high gain operation.

For low voltage operation, the inputs are taken to $V_{CC}$ through 51 Ω.

### IF Output

The IF is a differential open collector configuration which is designed to use over a wide frequency range for up conversion as well as down conversion.

### Input/Output Matching

It is desirable to use a RF ceramic or SAW filter before the mixer to provide image frequency rejection. The filter is selected based on cost, size and performance tradeoffs. Typical RF filters have 3.0 to 5.0 dB insertion loss. The PC board layout accommodates both ceramic and SAW RF filters which are offered by various suppliers such as Siemens, Toko and Murata.

Interface matching between the RF input, RF filter and the mixer will be required. The interface matching networks shown in the application circuit are designed for 50 Ω interfaces.

Differential to single–ended circuit configuration is shown in the test circuit. 6.0 dB of additional mixer gain can be achieved by conjugately matching the output of the MiniCircuits transformer to 50 Ω at the desired IF frequency. With narrowband IF output matching the mixer performance is 3.0 dB gain and 12 dB noise figure (see Narrowband 49 and 83 MHz IF Output Matching Options). Typical insertion loss of the Toko ceramic filter is 3.0 dB. Thus, the overall gain of the circuit is 0 dB with a 15 dB noise figure.

**Figure 9. Narrowband IF Output Matching with 16:1 Z Transformer and LC Network**

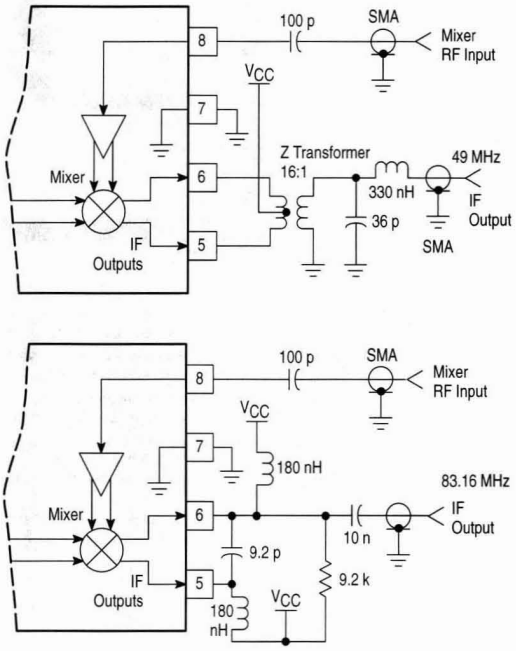



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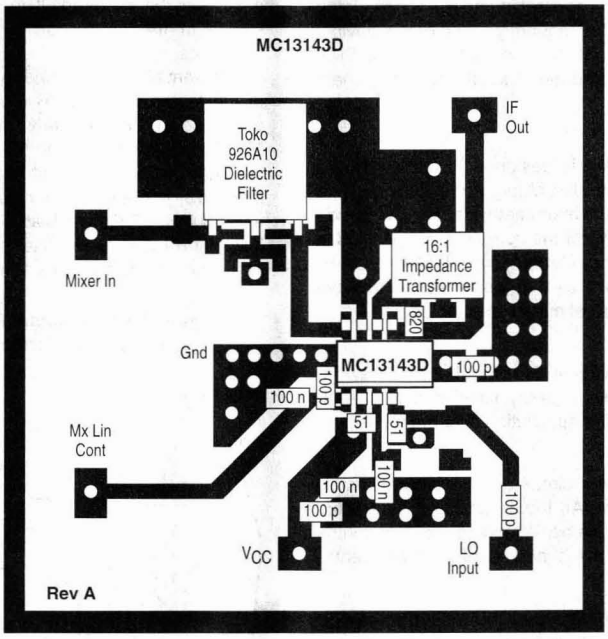
**Figure 10. Circuit Side Component Placement View**

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**NOTES:** 926.5 MHz preselect dielectric filter is Toko part # 4DFA–926A10; the 4DFA (2 and 3 pole SMD type) filters are available for applications in cellular and GSM, GPS, DECT, PHS, PCS and ISM bands at 902–928 MHz, 1.8–1.9 GHz at 2.4–2.5 GHz.

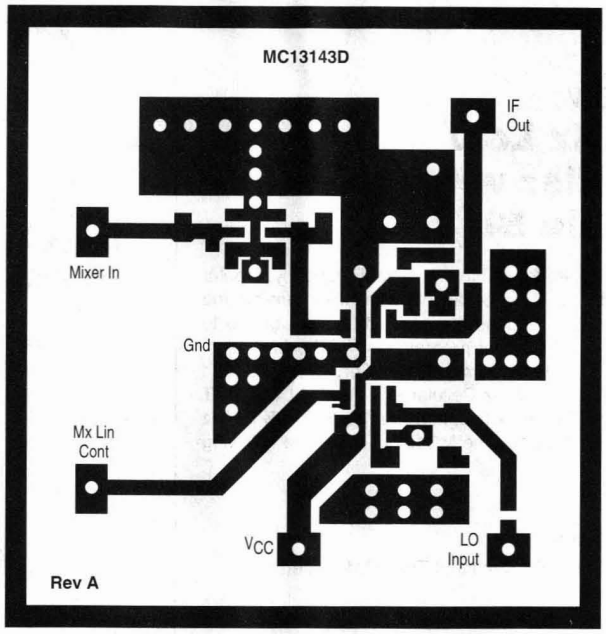
The PCB also accommodates a surface mount RF SAW filter in an eight or six pin ceramic package for the cellular base and handset frequencies. Recommended manufacturers are Siemens and Murata.

The PCB may also be used without a preselector filter; AC coupled to the mixer as shown in the test circuit schematic. All other external circuit components shown in the PCB layout above are the same as used in the test circuit schematic.

16:1 broadband impedance transformer is mini circuits part #TX16–R3T; it is in the leadless surface mount "TX" package. For a more selective narrowband match, a lowpass filter may be used after the transformer. The PCB is designed to accommodate lump inductors and capacitors in more selective narrowband matching of the mixer differential outputs to a single–ended output at a given IF frequency.

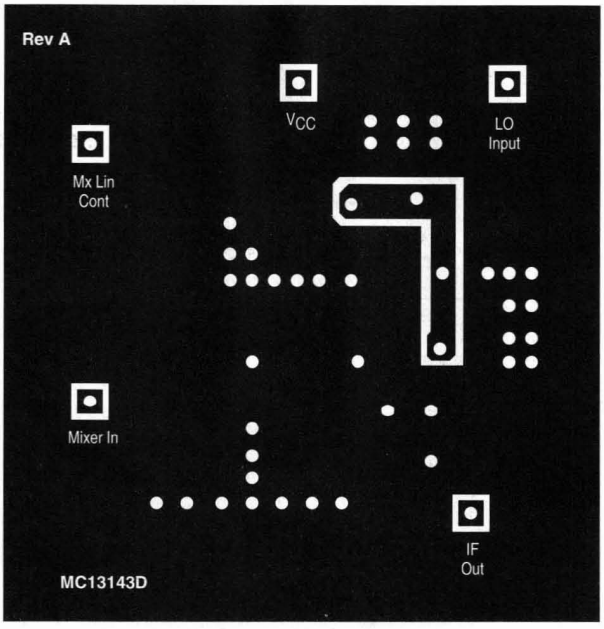
The local oscillator may also be driven in a differential configuration using a coaxial transformer. Recommended sources are the Toko Balun transformers type B4F, B5FL and B5F (SMD component).

**Figure 11. Circuit Side View**




**NOTES:** Critical dimensions are 50 mil centers lead to lead in SO–8 footprint.
Also line widths to labeled ports excluding $V_{CC}$ are 50 mil.

**Figure 12. Ground Side View**



MOTOROLA

# MC13144

*Product Preview*

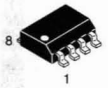
## VHF - 2.0 GHz Low Noise Amplifier with Programmable Bias

The MC13144 is designed in the Motorola High Frequency Bipolar MOSIAC V™ wafer process to provide excellent performance in analog and digital communication systems. It includes a cascoded LNA usable up to 2.0 GHz and at 1.8 Vdc, with 2 bit digital programming of the LNA bias. Targeted applications are in the UHF Family Radio Services, UHF and 800 MHz Special Mobile Radio, 800 MHz Cellular and GSM, PCS, DECT and PHS at 1.8 to 2.0 GHz and Cordless Telephones in the 902 to 928 MHz band covered by FCC Title 47; Part 15. The MC13144 offers the following features:

- 17 dB Gain at 900 MHz
- 1.4 dB Noise Figure at 900 MHz
- 1.0 dB Compression Point of –7.0 dBm; Input Third Order Intercept Point of –5.0 dBm
- Low Operating Supply Voltage (1.8 to 6.0 Vdc)
- Programmable Bias with Enable 1 and Enable 2
- Enable 1 and Enable 2 Programmed High for Optimal Noise Figure and Gain Associated with NF
- Can Override Enable and Externally Program In Up to 15 mA

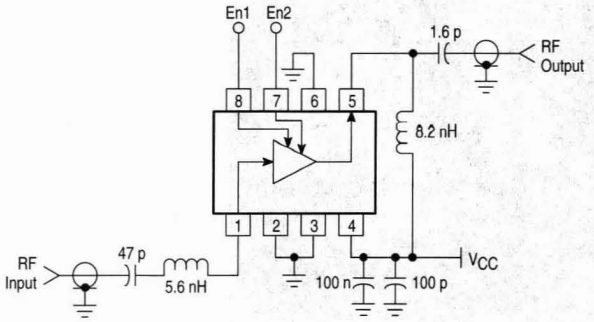
**VHF – 2.0 GHz LOW NOISE AMPLIFIER WITH PROGRAMMABLE BIAS**

**SEMICONDUCTOR TECHNICAL DATA**



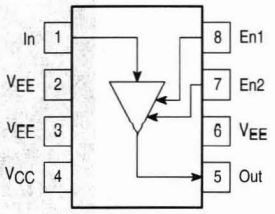

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**Typical Application as 900 MHz Low Noise Amplifier**




This device contains 67 active transistors.

**PIN CONNECTIONS AND FUNCTIONAL BLOCK DIAGRAM**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13144D | $T_A$ = – 40° to +85°C | SO–8 |

8

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$(max) | 7.0 | Vdc |
| Junction Temperature | $T_{Jmax}$ | +150 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**NOTES:** 1. Devices should not be operated at or outside these values. The "Recommended Operating Conditions" provide for actual device operation.

2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 4 | $V_{CC}$ | 1.8 to 6.0 | Vdc |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C; $V_{CC}$ = 3.0 Vdc; No Input Signal)

| Characteristic | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Supply Current (Power Down) | En1 = En2 = Low | 4 | $I_{CC}$ | – | 100 | – | pA |
| Supply Current (Power Up) | En1 = High<br>En2 = Low | 4 | $I_{CC}$ | – | 4.2 | – | mA |

## AC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C; $V_{CC}$ = 3.0 Vdc; $f_{RF}$ = 926.5 MHz; En1 = High; En2 = Low)

| Characteristic | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Amplifier Gain (50 Ω Insertion Gain) | – | 1, 5 | $S_{21}{}^2$ | – | 12 | – | dB |
| Amplifier Reverse Isolation | – | 5, 1 | S12 | – | –35 | – | dB |
| Amplifier Input Return Loss | – | 1 | $\Gamma in_{amp}$ | – | –10 | – | dB |
| Amplifier Output Return Loss | – | 5 | $\Gamma out_{amp}$ | – | –15 | – | dB |
| Input 3rd Order Intercept Point | df = 100 kHz<br>df = 1.0 MHz | 1, 5<br>1, 5 | IIP3<br>IIP3 | –<br>– | –12<br>–5.0 | –<br>– | dBm<br>dBm |
| Amplifier Gain @ NF | See Typical Application Figure | 1, 5 | $G_{NF}$ | – | 17 | – | dB |
| Amplifier Noise Figure | See Typical Application Figure | 1, 5 | NF | – | 1.4 | – | dB |

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## CIRCUIT DESCRIPTION

### General

The MC13144 is a low noise amplifier with programmable bias. This device is designated for use in the front end section in analog and digital FM systems such as Wireless Local Area Network (LAN), Digital European Cordless Telephone (DECT), PHS, PCS, GPS, Cellular, UHF and 800 MHz Special Mobile Radio (SMR), UHF Family Radio Services and 902 to 928 MHz cordless telephones.

### Current Regulation/Enable

Temperature compensating voltage independent current regulation is digitally controlled by a 2 bit programmable bias/enable circuit.

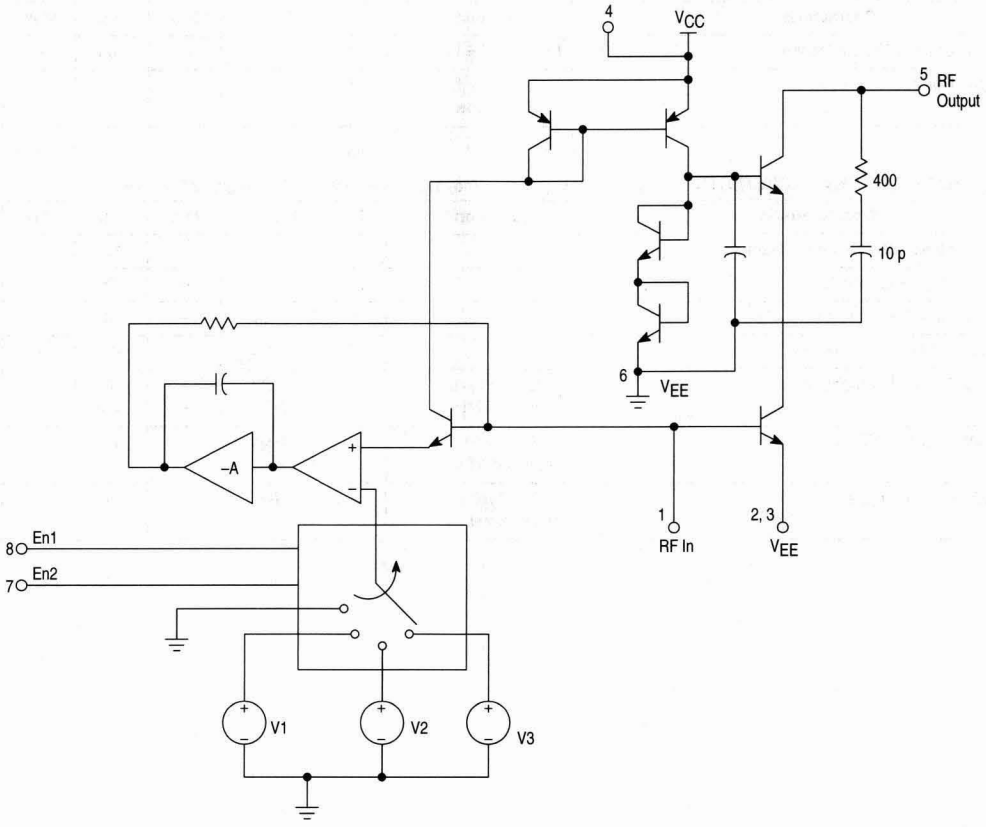
### LNA

The LNA is a unique and patented cascode amplifier with digitally (2 bit) programmable bias (see Internal Circuit Schematic). Typical gain of the LNA is 17 dB for minimum noise figure of 1.4 dB at 900 MHz.

### Programmable Bias/Enable Circuit

This unique circuit allows for 3 bias levels and a standby mode in which the LNA can be externally biased as desired.

**Figure 1. MC13144 Internal Circuit***




**NOTE:** * The MC13144 uses a unique and patent pending circuit topology.

## APPLICATIONS INFORMATION

### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The PC board layout accommodates all SMT components on the circuit side (see Circuit Side Component Placement View).

### Component Selection

The evaluation PC board is laid out for the 4DFA (2 pole SMD Type) and 4DFB (3 pole SMD Type) filters which are available for applications in Cellular and GSM, GPS (1.2 to 1.5 GHz), DECT, PHS and PCS (1.8 to 2.0 GHz) and ISM Bands (902 to 928 MHz and 2.4 to 2.5 GHz). In the 926.5 MHz Application Circuit, a ceramic deielectric filter is used (Toko part # 4DFA–926A10).

### LNA Input/Output

The LNA input impedance is the base of a common emitter cascode amplifier. The LNA output is the collector of the cascode stage and it is loaded with a series resistor of 400 Ω and a capacitor of 10 pF to provide stability.

### Digitally Programmable Bias/Enable

The LNA is enabled by a 2 bit (En1 and En2) programmable bias circuit. The internal circuit shows the comparator circuit which programs the internal regulator. The logic table below shows the bias and typical performance.

| $I_{CC}$/Gain | En2 Low | En2 High |
|---|---|---|
| En1 Low | 0 mA/0 dB | 2.0 mA/13 dB |
| En1 High | 4.2 mA/17.0 dB | 9.4 mA/18 dB |

### Input/Output Matching

A typical application at 900 MHz yields 17 dB gain and 1.4 dB noise figure. In this circuit a series inductor of 5.6 nH is used to match the input and a shunt inductor of 8.2 nH which also serves as an RFC and a series capacitor of 0.9 p is used to match the LNA output to 50 Ω load impedance.

It may be desirable to use a RF ceramic or SAW filter after the LNA when driving a mixer to provide image frequency rejection. The image filter is selected based on cost, size and performance tradeoffs. Typical RF filters have 3.0 to 5.0 dB insertion loss. Interface matching between the RF input, RF filter and the mixer is shown in Application Circuit and the Component Placement View.

**Figure 2. MC13144D Application Circuit**
(926.5 MHz)

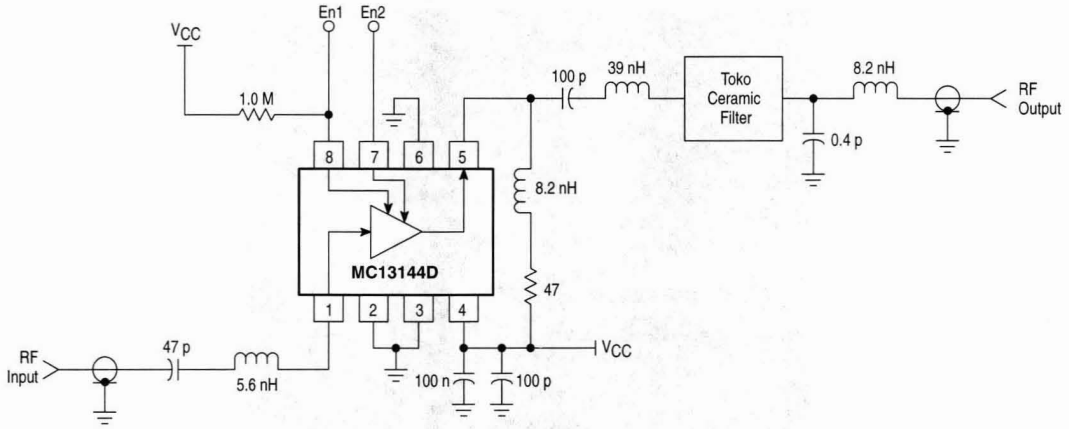



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**Figure 3. Circuit Side Component Placement View**

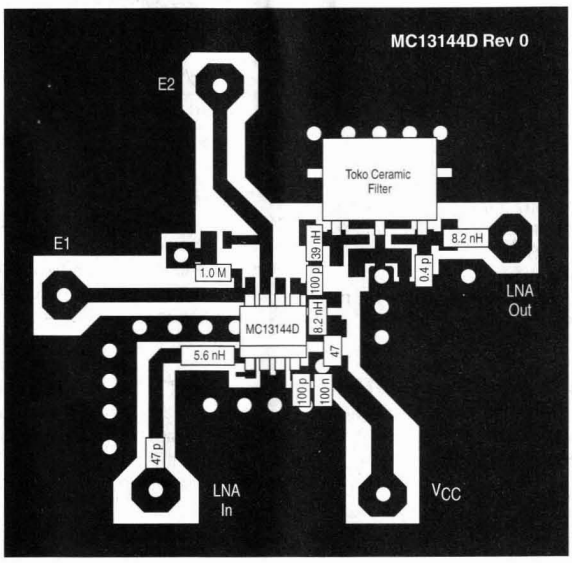


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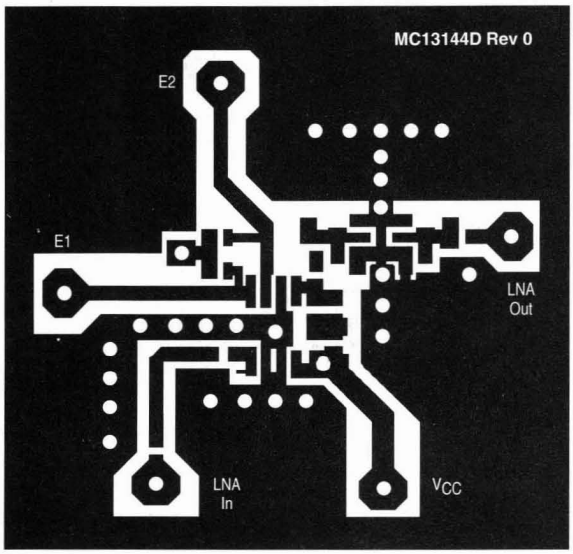
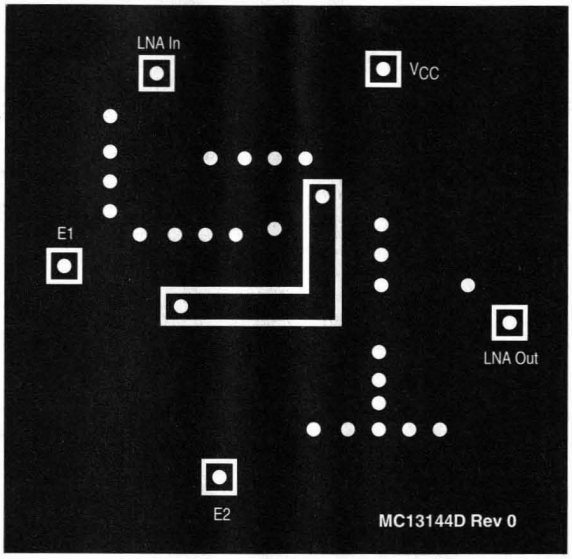
**Figure 4. Circuit Side View**




**NOTES:** Critical dimensions are 50 MIL centers lead to lead in SO–8 footprint.
Also line widths to labeled ports excluding $V_{CC}$, E1 and E2 are 50 MIL (0.050 inch).
FR4 PCB, 1/32 inch.

**Figure 5. Ground Side View**




**NOTES:** FR4 PCB, 1/32 inch.

MOTOROLA

# MC13150

# Narrowband FM Coilless Detector IF Subsystem

**NARROWBAND FM COILLESS DETECTOR IF SUBSYSTEM FOR CELLULAR AND ANALOG APPLICATIONS**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13150 is a narrowband FM IF subsystem targeted at cellular and other analog applications. Excellent high frequency performance is achieved, with low cost, through use of Motorola's MOSAIC 1.5™ RF bipolar process. The MC13150 has an onboard Colpitts VCO for Crystal controlled second LO in dual conversion receivers. The mixer is a double balanced configuration with excellent third order intercept. It is useful to beyond 200 MHz. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. The quadrature detector is a unique design eliminating the conventional tunable quadrature coil.

Applications for the MC13150 include cellular, CT–1 900 MHz cordless telephone, data links and other radio systems utilizing narrowband FM modulation.

- Linear Coilless Detector
- Adjustable Demodulator Bandwidth
- 2.5 to 6.0 Vdc Operation
- Low Drain Current: < 2.0 mA
- Typical Sensitivity of 2.0 μV for 12 dB SINAD
- IIP3, Input Third Order Intercept Point of 0 dBm
- RSSI Range of Greater Than 100 dB
- Internal 1.4 kΩ Terminations for 455 kHz Filters
- Split IF for Improved Filtering and Extended RSSI Range

**FTA SUFFIX**
PLASTIC PACKAGE
CASE 977
(Thin QFP)

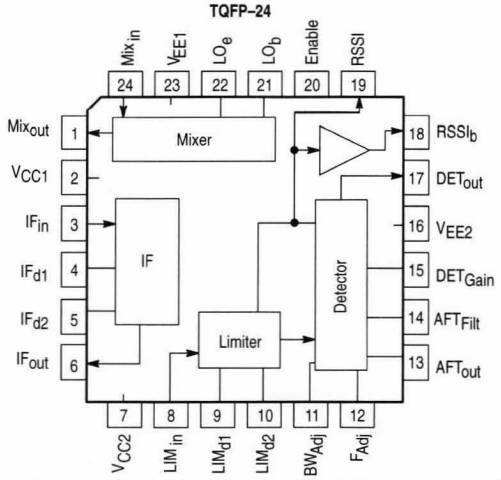
**FTB SUFFIX**
PLASTIC PACKAGE
CASE 873
(Thin QFP)

**ORDERING INFORMATION**

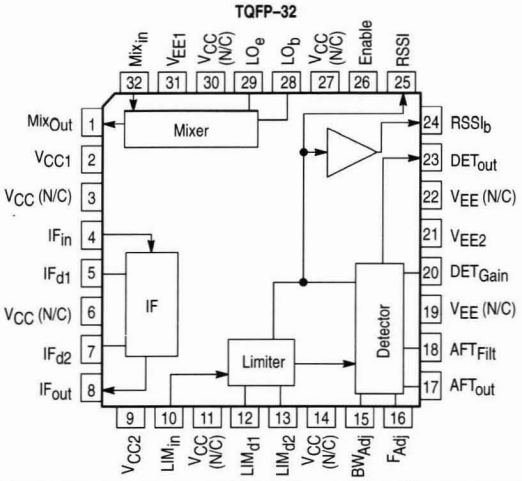
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13150FTA | $T_A$ = –40 ° to +85°C | TQFP–24 |
| MC13150FTB | | TQFP–32 |

**PIN CONNECTIONS**

TQFP-24




TQFP-32

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## MAXIMUM RATINGS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 2, 9 | $V_{CC}$(max) | 6.5 | Vdc |
| Junction Temperature | – | $T_{Jmax}$ | +150 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to +150 | °C |

**NOTE:** 1. Devices should not be operated at or outside these values. The "Recommended Operating Limits" provide for actual device operation.

2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage $T_A$ = 25°C<br>– 40°C ≤ $T_A$ ≤ 85°C<br>(See Figure 22) | 2, 9<br>21, 31 | $V_{CC}$<br>$V_{EE}$ | 2.5 to 6.0<br>0 | Vdc |
| Input Frequency | 32 | $f_{in}$ | 10 to 500 | MHz |
| Ambient Temperature Range | - | $T_A$ | – 40 to + 85 | °C |
| Input Signal Level | 32 | $V_{in}$ | 0 | dBm |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = 3.0 Vdc, No Input Signal.)

| Characteristics | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Total Drain Current (See Figure 2) | $V_S$ = 3.0 Vdc | 2 + 9 | $I_{TOTAL}$ | – | 1.7 | 3.0 | mA |
| Supply Current, Power Down (See Figure 3) | – | 2 + 9 | – | – | 40 | – | nA |

## AC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_S$ = 3.0 Vdc, $f_{RF}$ = 50 MHz, $f_{LO}$ = 50.455 MHz, LO Level = –10 dBm, see Figure 1 Test Circuit*, unless otherwise specified.)

| Characteristics | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| 12 dB SINAD Sensitivity (See Figure 15) | $f_{mod}$ = 1.0 kHz; $f_{dev}$ = ± 5.0 kHz | 32 | – | – | –100 | – | dBm |
| RSSI Dynamic Range (See Figure 7) | – | 25 | – | – | 100 | – | dB |
| Input 1.0 dB Compression Point<br>Input 3rd Order Intercept Point (See Figure 18) | –<br>– | –<br>– | 1.0 dB C. Pt.<br>IIP3 | –<br>– | –11<br>–1.0 | –<br>– | dBm |
| Coilless Detector Bandwidth Adjust (See Figure 11) | Measured with No IF Filters | – | ΔBW adj | – | 26 | – | kHz/μA |
| **MIXER** | | | | | | | |
| Conversion Voltage Gain (See Figure 5) | $P_{in}$ = – 30 dBm; PLO = –10 dBm | 32 | – | – | 10 | – | dB |
| Mixer Input Impedance | Single–Ended | 32 | – | – | 200 | – | Ω |
| Mixer Output Impedance | – | 1 | – | – | 1.5 | – | kΩ |
| **LOCAL OSCILLATOR** | | | | | | | |
| LO Emitter Current (See Figure 26) | – | 29 | – | 30 | 63 | 100 | μA |
| **IF & LIMITING AMPLIFIERS SECTION** | | | | | | | |
| IF and Limiter RSSI Slope | Figure 7 | 25 | – | – | 0.4 | – | μA/dB |
| IF Gain | Figure 8 | 4, 8 | – | – | 42 | – | dB |
| IF Input & Output Impedance | – | 4, 8 | – | – | 1.5 | – | kΩ |
| Limiter Input Impedance | – | 10 | – | – | 1.5 | – | kΩ |
| Limiter Gain | – | – | – | – | 96 | – | dB |

* Figure 1 Test Circuit uses positive ($V_{CC}$) Ground.

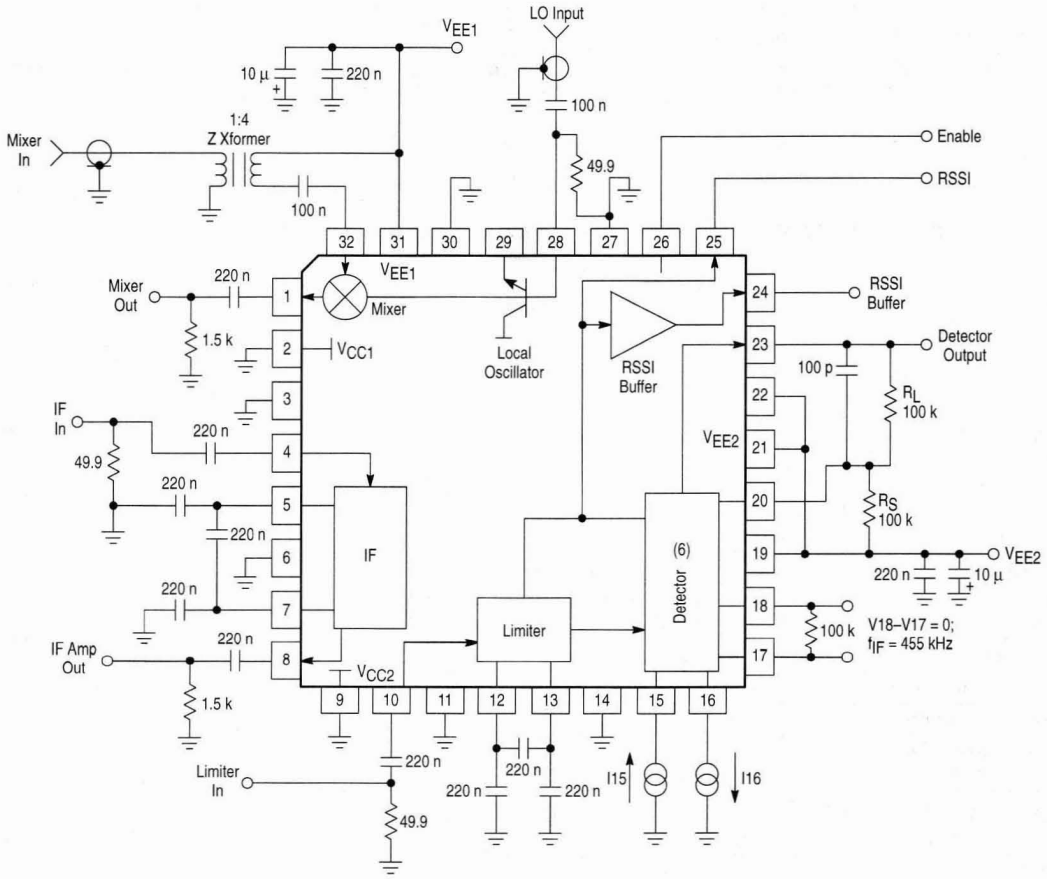
8

**AC ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_S$ = 3.0 Vdc, $f_{RF}$ = 50 MHz, $f_{LO}$ = 50.455 MHz, LO Level = –10 dBm, see Figure 1 Test Circuit*, unless otherwise specified.)

| Characteristics | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **DETECTOR** | | | | | | | |
| Frequency Adjust Current | Figure 9, $f_{IF}$ = 455 kHz | 16 | – | 41 | 49 | 56 | µA |
| Frequency Adjust Voltage | Figure 10, $f_{IF}$ = 455 kHz | 16 | – | 600 | 650 | 700 | mVdc |
| Bandwidth Adjust Voltage | Figure 12, $I_{15}$ = 1.0 µA | 15 | – | – | 570 | – | mVdc |
| Detector DC Output Voltage (See Figure 25) | – | 23 | – | – | 1.36 | – | Vdc |
| Recovered Audio Voltage | $f_{dev}$ = ±3.0 kHz | 23 | – | 85 | 122 | 175 | mVrms |

* Figure 1 Test Circuit uses positive ($V_{CC}$) Ground.

**Figure 1. Test Circuit**




This device contains 292 active transistors.

## MC13150 CIRCUIT DESCRIPTION

### General

The MC13150 is a very low power single conversion narrowband FM receiver incorporating a split IF. This device is designated for use as the backend in analog narrowband FM systems such as cellular, 900 MHz cordless phones and narrowband data links with data rates up to 9.6 k baud. It contains a mixer, oscillator, extended range received signal strength indicator (RSSI), RSSI buffer, IF amplifier, limiting IF, a unique coilless quadrature detector and a device enable function (see Package Pin Outs/Block Diagram).

### Low Current Operation

The MC13150 is designed for battery and portable applications. Supply current is typically 1.7 mAdc at 3.0 Vdc. Figure 2 shows the supply current versus supply voltage.

### Enable

The enable function is provided for battery powered operation. The enabled pin is pulled down to enable the regulators. Figure 3 shows the supply current versus enable voltage, $V_{enable}$ (relative to $V_{CC}$) needed to enable the device. Note that the device is fully enabled at $V_{CC} - 1.3$ Vdc. Figure 4 shows the relationship of enable current, $I_{enable}$ to enable voltage, $V_{enable}$.

### Mixer

The mixer is a double–balanced four quadrant multiplier and is designed to work up to 500 MHz. It has a single ended input. Figure 5 shows the mixer gain and saturated output response as a function of input signal drive and for –10 dBm LO drive level. This is measured in the application circuit shown in Figure 15 in which a single LC matching network is used. Since the single–ended input impedance of the mixer is 200 Ω, an alternate solution uses a 1:4 impedance transformer to match the mixer to 50 Ω input impedance. The linear voltage gain of the mixer alone is approximately 4.0 dB (plus an additional 6.0 dB for the transformer). Figure 6 shows the mixer gain versus the LO input level for various mixer input levels at 50 MHz RF input.

The buffered output of the mixer is internally loaded, resulting in an output impedance of 1.5 kΩ.

### Local Oscillator

The on–chip transistor operates with crystal and LC resonant elements up to 220 MHz. Series resonant, overtone crystals are used to achieve excellent local oscillator stability. 3rd overtone crystals are used through about 65 to 70 MHz. Operation from 70 MHz up to 200 MHz is feasible using the on–chip transistor with a 5th or 7th overtone crystal. To enhance operation using an overtone crystal, the internal transistor's bias is increased by adding an external resistor from Pin 29 (in 32 pin QFP package) to $V_{EE}$ to keep the oscillator on continuously or it may be taken to the enable pin to shut it off when the receiver is disabled. –10 dBm of local oscillator drive is needed to adequately drive the mixer (Figure 6). The oscillator configurations specified above are described in the application section.

### RSSI

The received signal strength indicator (RSSI) output is a current proportional to the log of the received signal amplitude. The RSSI current output is derived by summing the currents from the IF and limiting amplifier stages. An external resistor at Pin 25 (in 32 pin QFP package) sets the voltage range or swing of the RSSI output voltage. Linearity of the RSSI is optimized by using external ceramic bandpass filters which have an insertion loss of 4.0 dB. The RSSI circuit is designed to provide 100+ dB of dynamic range with temperature compensation (see Figures 7 and 23 which show the RSSI response of the applications circuit).

### RSSI Buffer

The RSSI buffer has limitations in what loads it can drive. It can pull loads well towards the positive and negative supplies, but has problems pulling the load away from the supplies. The load should be biased at half supply to overcome this limitation.

**Figure 2. Supply Current versus Supply Voltage**

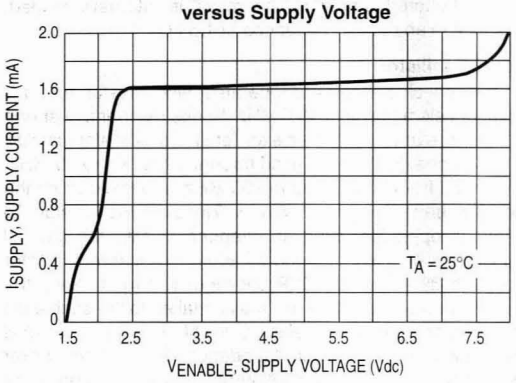



**Figure 3. Supply Current versus Enable Voltage**

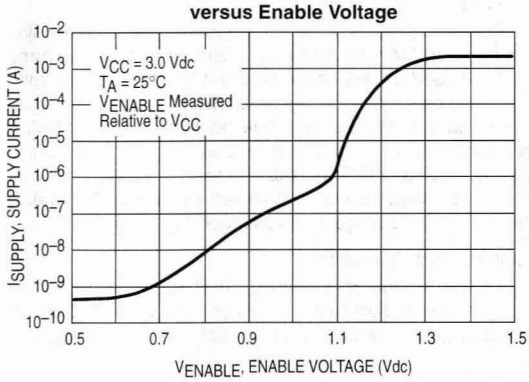



**Figure 4. Enable Current versus Enable Voltage**

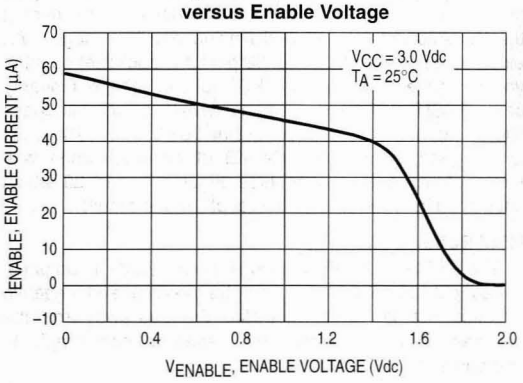



**Figure 5. Mixer IF Output Level versus RF Input Level**

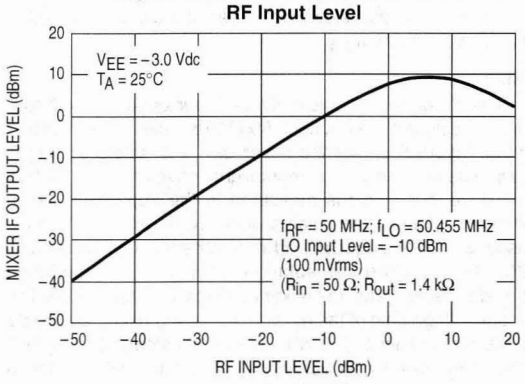



**Figure 6. Mixer IF Output Level versus Local Oscillator Input Level**

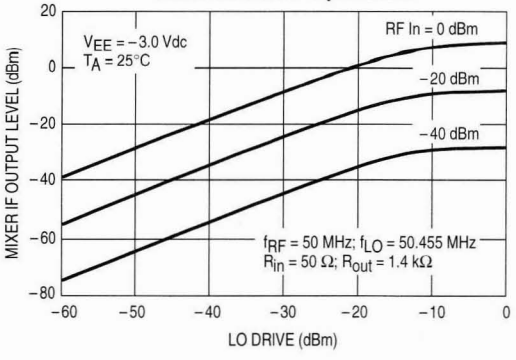
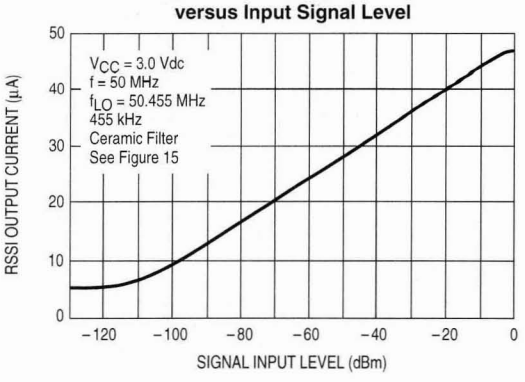



**Figure 7. RSSI Output Current versus Input Signal Level**

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### IF Amplifier

The first IF amplifier section is composed of three differential stages. This section has internal dc feedback and external input decoupling for improved symmetry and stability. The total gain of the IF amplifier block is approximately 42 dB at 455 kHz. Figure 8 shows the gain of the IF amplifier as a function of the IF frequency.

The fixed internal input impedance is 1.5 kΩ; it is designed for applications where a 455 kHz ceramic filter is used and no external output matching is necessary since the filter requires a 1.5 kΩ source and load impedance.

Overall RSSI linearity is dependent on having total midband attenuation of 10 dB (4.0 dB insertion loss plus 6.0 dB impedance matching loss) for the filter. The output of the IF amplifier is buffered and the impedance is 1.5 kΩ.

### Limiter

The limiter section is similar to the IF amplifier section except that six stages are used. The fixed internal input impedance is 1.5 kΩ. The total gain of the limiting amplifier section is approximately 96 dB. This IF limiting amplifier section internally drives the quadrature detector section.

**Figure 8. IF Amplifier Gain versus IF Frequency**

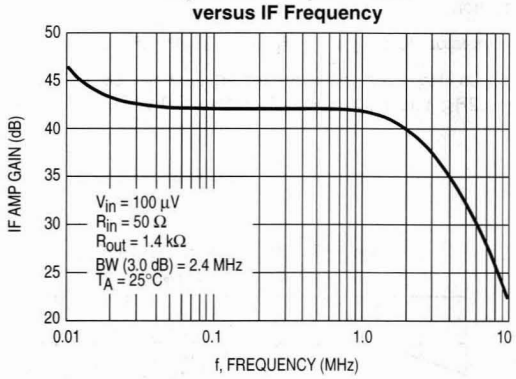



**Figure 9. $F_{adj}$ Current versus IF Frequency**

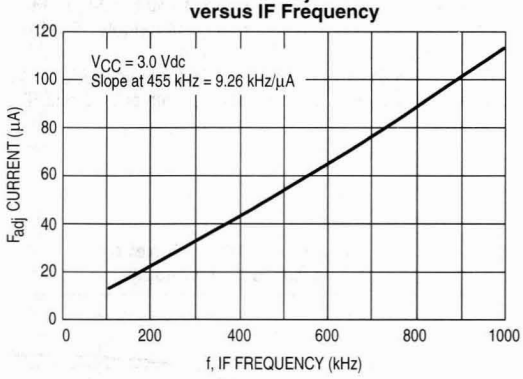



**Figure 10. $F_{adj}$ Voltage versus $F_{adj}$ Current**

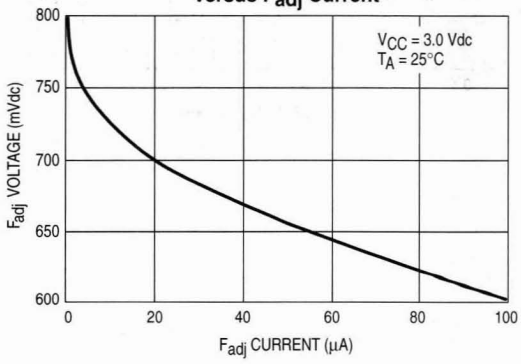
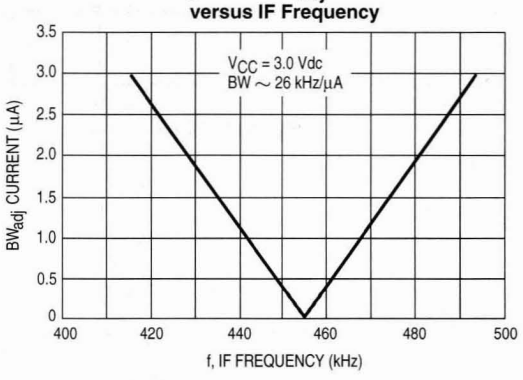



**Figure 11. $BW_{adj}$ Current versus IF Frequency**

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**Coilless Detector**

The quadrature detector is similar to a PLL. There is an internal oscillator running at the IF frequency and two detector outputs. One is used to deliver the audio signal and the other one is filtered and used to tune the oscillator.

The oscillator frequency is set by an external resistor at the $F_{adj}$ pin. Figure 9 shows the control current required for a particular frequency; Figure 10 shows the pin voltage at that current. From this the value of $R_F$ is chosen. For example, 455 kHz would require a current of around 50 μA. The pin voltage (Pin 16 in the 32 pin QFP package) is around 655mV giving a resistor of 13.1 kΩ. Choosing 12 kΩ as the nearest standard value gives a current of approximately 55 μA. The 5.0 μA difference can be taken up by the tuning resistor, $R_T$.

The best nominal frequency for the $AFT_{out}$ pin (Pin 17) would be half supply. A supply voltage of 3.0 Vdc suggests a resistor value of (1.5 – 0.655)V/5μA = 169 kΩ. Choosing 150 kΩ would give a tuning current of 3/150 k = 20 μA. From Figure 9 this would give a tuning range of roughly 10 kHz/μA or ± 100 kHz which should be adequate.

The bandwidth can be adjusted with the help of Figure 11. For example, 1.0 μA would give a bandwidth of ± 13 kHz. The voltage across the bandwidth resistor, $R_B$ from Figure 12 is $V_{CC}$ – 2.44 Vdc = 0.56 Vdc for $V_{CC}$ = 3.0 Vdc., so $R_B$ = 0.56V/1.0 μA = 560 kΩ. Actually the locking range will be ±13 kHz while the audio bandwidth will be approximately ±8.4 kHz due to an internal filter capacitor. This is verified in Figure 13. For some applications it may be desirable that the audio bandwidth is increased; this is done by reducing $R_B$. Reducing $R_B$ widens the detector bandwidth and improves the distortion at high input levels at the expense of 12 dB SINAD sensitivity. The low frequency 3.0dB point is set by the tuning circuit such that the product

$$R_T C_T = 0.68/f3dB.$$

So, for example, 150 k and 1.0 μF give a 3.0 dB point of 4.5 Hz. The recovered audio is set by $R_L$ to give roughly 50mV per kHz deviation per 100 k of resistance. The dc level can be shifted by $R_S$ from the nominal 0.68 V by the following equation:

$$\text{Detector DC Output} = ((R_L + R_S)/R_S)\ 0.68\ \text{Vdc}$$

Thus, $R_S = R_L$ sets the output at 2 x 0.68 = 1.36 V; $R_L = 2R_S$ sets the output at 3 x 0.68 = 2.0 V.

**Figure 12. $BW_{adj}$ Current versus $BW_{adj}$ Voltage**

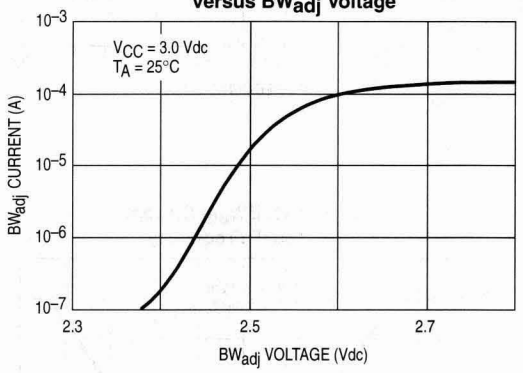
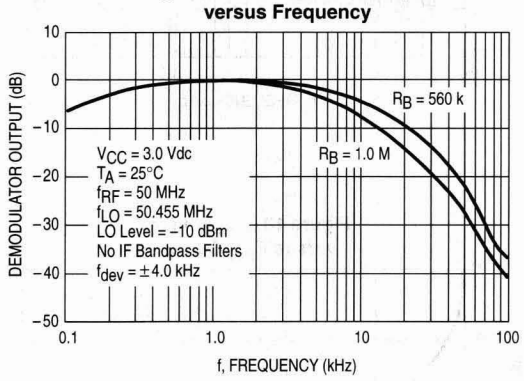



**Figure 13. Demodulator Output versus Frequency**



## APPLICATIONS INFORMATION

### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The center section of the board provides an area for attaching all SMT components to the circuit side and radial leaded components to the component ground side (see Figures 29 and 30). Additionally, the peripheral area surrounding the RF core provides pads to add supporting and interface circuitry as a particular application dictates. There is an area dedicated for a LNA preamp. This evaluation board will be discussed and referenced in this section.

### Component Selection

The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers and coil types. The applications circuit schematic (Figure 15) specifies particular components that were used to achieve the results shown in the typical curves but equivalent components should give similar results. Component placement views are shown in Figures 27 and 28 for the application circuit in Figure 15 and for the 83.616 MHz crystal oscillator circuit in Figure 16.

### Input Matching Components

The input matching circuit shown in the application circuit schematic (Figure 15) is a series L, shunt C single L section which is used to match the mixer input to 50 Ω. An alternative input network may use 1:4 surface mount transformers or BALUNs. The 12 dB SINAD sensitivity using the 1:4 impedance transformer is typically −100 dBm for $f_{mod}$ = 1.0 kHz and $f_{dev}$ = ±5.0 kHz at $f_{in}$ = 50 MHz and $f_{LO}$ = 50.455 MHz (see Figure 14).

It is desirable to use a SAW filter before the mixer to provide additional selectivity and adjacent channel rejection and improved sensitivity. SAW filters sourced from Toko (Part # SWS083GBWA) and Murata (Part # SAF83.16MA51X) are excellent choices to easily interface with the MC13150 mixer. They are packaged in a 12 pin low profile surface mount ceramic package. The center frequency is 83.161 MHz and the 3.0 dB bandwidth is 30 kHz.

**Figure 14. S+N+D, N+D, N, 30% AMR versus Input Signal Level**

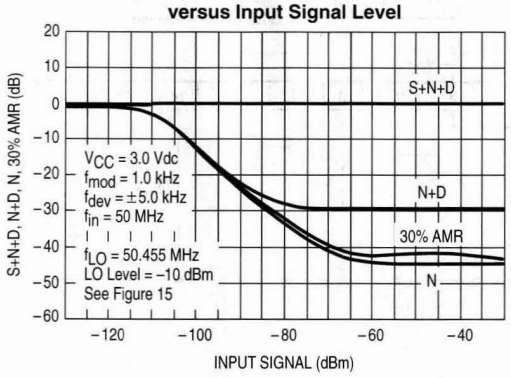



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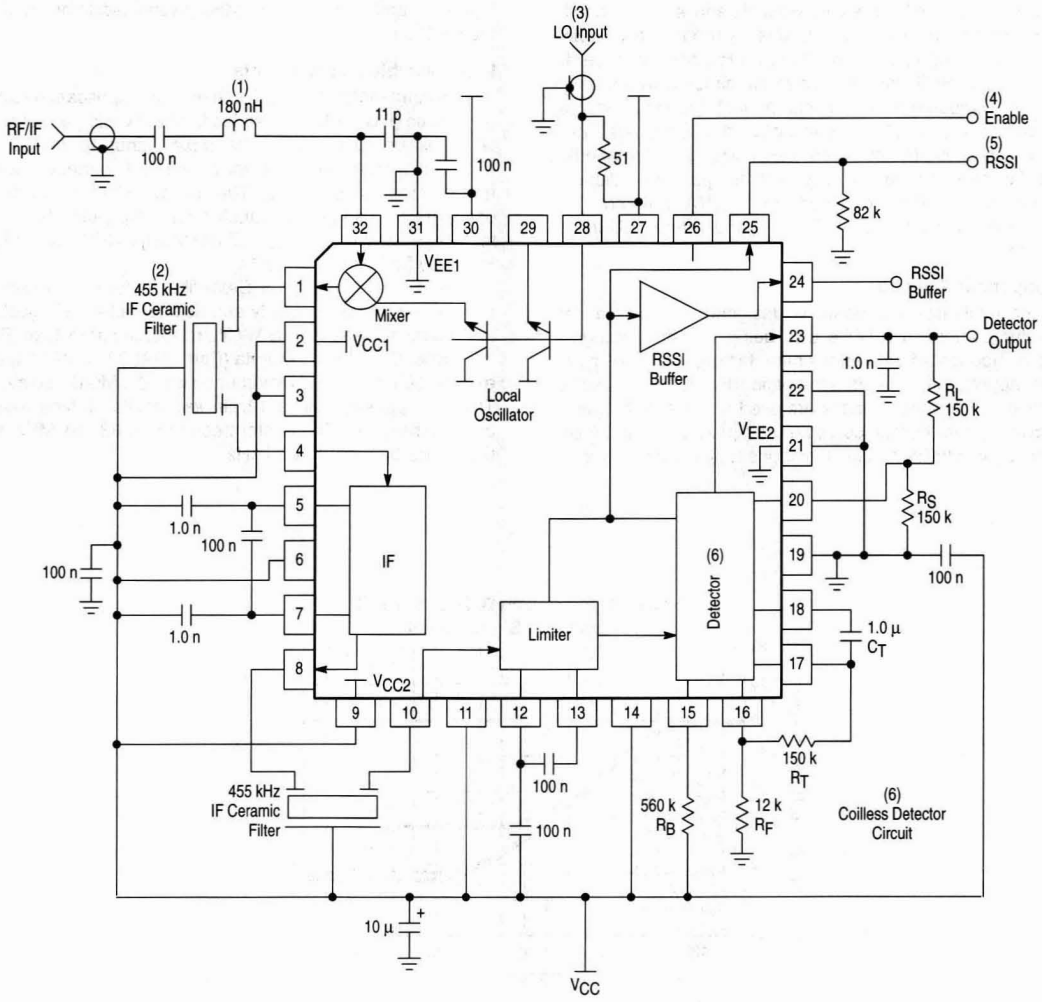
**Figure 15. Application Circuit**




**NOTES:** 1. Alternate solution is 1:4 impedance transformer (sources include Mini Circuits, Coilcraft and Toko).
2. 455 kHz ceramic filters (source Murata CFU455 series which are selected for various bandwidths).
3. For external LO source, a 51 Ω pull–up resistor is used to bias the base of the on–board transistor as shown in Figure 15. Designer may provide local oscillator with 3rd, 5th, or 7th overtone crystal oscillator circuit. The PC board is laid out to accommodate external components needed for a Butler emitter coupled crystal oscillator (see Figure 16).
4. Enable IC by switching the pin to $V_{EE}$.
5. The resistor is chosen to set the range of RSSI voltage output swing.
6. Details regarding the external components to setup the coilless detector are provided in the application section.

## Local Oscillators

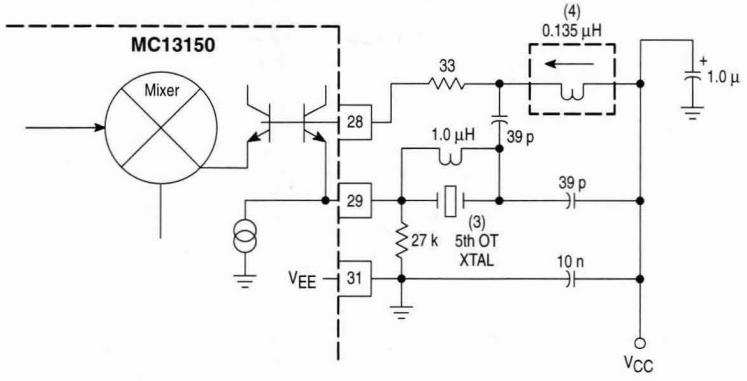
### HF & VHF Applications

In the application schematic, an external sourced local oscillator is utilized in which the base is biased via a 51 Ω resistor to $V_{CC}$. However, the on–chip grounded collector transistor may be used for HF and VHF local oscillators with higher order overtone crystals. Figure 16 shows a 5th overtone oscillator at 83.616 MHz. The circuit uses a Butler overtone oscillator configuration. The amplifier is an emitter follower. The crystal is driven from the emitter and is coupled to the high impedance base through a capacitive tap network. Operation at the desired overtone frequency is ensured by the parallel resonant circuit formed by the variable inductor and the tap capacitors and parasitic capacitances of the on–chip transistor and PC board. The variable inductor specified in the schematic could be replaced with a high tolerance, high Q ceramic or air wound surface mount component if the other components have tight enough tolerances. A variable inductor provides an adjustment for gain and frequency of the resonant tank ensuring lock up and start–up of the crystal oscillator. The overtone crystal is chosen with ESR of typically 80 Ω and 120 Ω maximum; if the resistive loss in the crystal is too high the performance of oscillator may be impacted by lower gain margins.

A series LC network to ac ground (which is $V_{CC}$) is comprised of the inductance of the base lead of the on–chip transistor and PC board traces and tap capacitors. Parasitic oscillations often occur in the 200 to 800 MHz range. A small resistor is placed in series with the base (Pin 28) to cancel the negative resistance associated with this undesired mode of oscillation. Since the base input impedance is so large, a small resistor in the range of 27 to 68 Ω has very little effect on the desired Butler mode of oscillation.

The crystal parallel capacitance, $C_O$, provides a feedback path that is low enough in reactance at frequencies of 5th overtones or higher to cause trouble. $C_O$ has little effect near resonance because of the low impedance of the crystal motional arm ($R_m$–$L_m$–$C_m$). As the tunable inductor, which forms the resonant tank with the tap capacitors, is tuned off the crystal resonant frequency, it may be difficult to tell if the oscillation is under crystal control. Frequency jumps may occur as the inductor is tuned. In order to eliminate this behavior an inductor, $L_O$, is placed in parallel with the crystal. $L_O$ is chosen to resonant with the crystal parallel capacitance, $C_O$, at the desired operation frequency. The inductor provides a feedback path at frequencies well below resonance; however, the parallel tank network of the tap capacitors and tunable inductor prevent oscillation at these frequencies.

**Figure 16. MC13150FTB Overtone Oscillator**
**$f_{RF}$ = 83.16 MHz; $f_{LO}$ = 83.616 MHz**
**5th Overtone Crystal Oscillator**



### Receiver Design Considerations

The curves of signal levels at various portions of the application receiver with respect to RF input level are shown in Figure 17. This information helps determine the network topology and gain blocks required ahead of the MC13150 to achieve the desired sensitivity and dynamic range of the receiver system. The PCB is laid out to accommodate a low noise preamp followed by the 83.16 MHz SAW filter. In the application circuit (Figure 15), the input 1.0 dB compression point is –10 dBm and the input third order intercept (IP3) performance of the system is approximately 0 dBm (see Figure 18).

### Typical Performance Over Temperature

Figures 19–26 show the device performance over temperature.

**Figure 17. Signal Levels versus RF Input Signal Level**

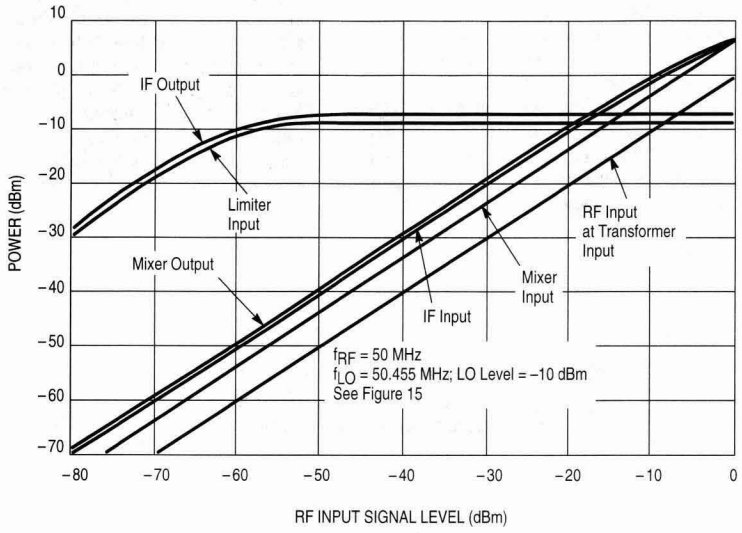



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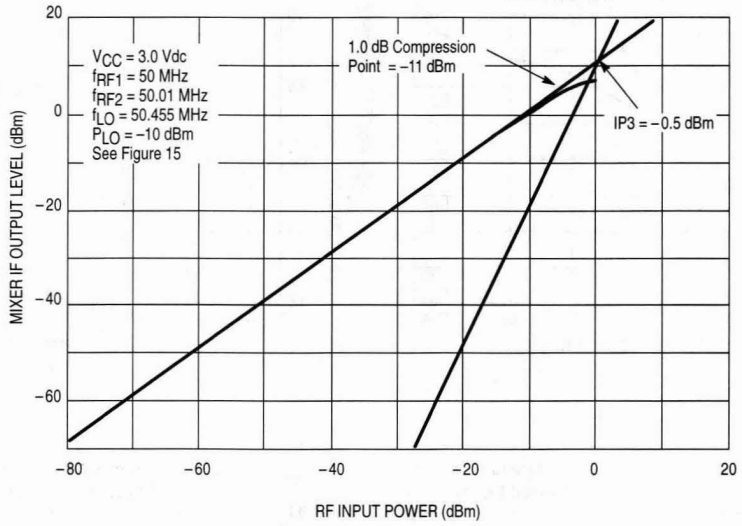
**Figure 18. 1.0 dB Compression Point and Input Third Order Intercept Point versus Input Power**

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## TYPICAL PERFORMANCE OVER TEMPERATURE

**Figure 19. Supply Current, $I_{VEE1}$ versus Signal Input Level**

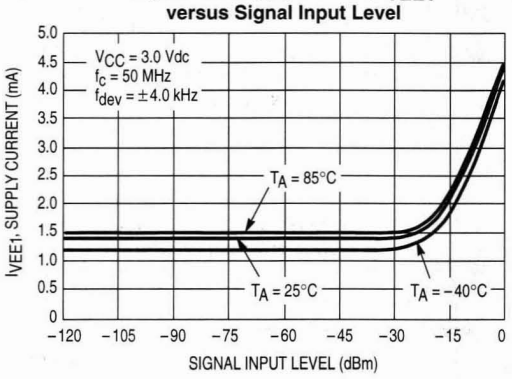
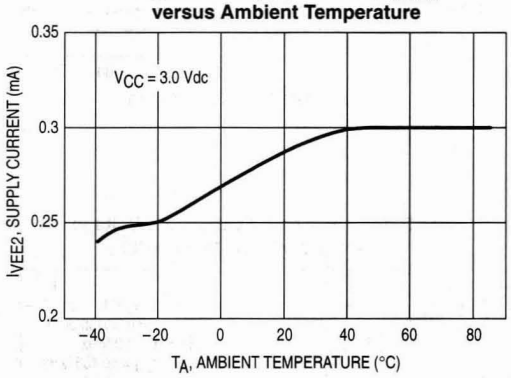



**Figure 20. Supply Current, $I_{VEE2}$ versus Ambient Temperature**



## TYPICAL PERFORMANCE OVER TEMPERATURE

**Figure 21. Total Supply Current versus Ambient Temperature**

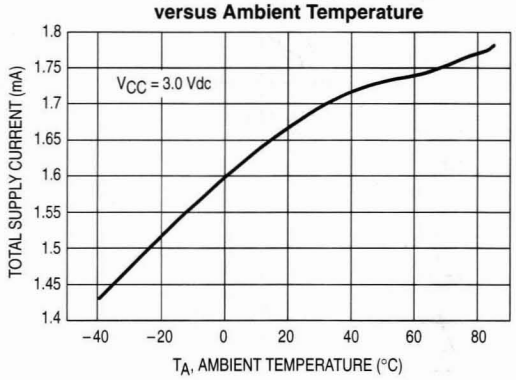



**Figure 22. Minimum Supply Voltage versus Ambient Temperature**

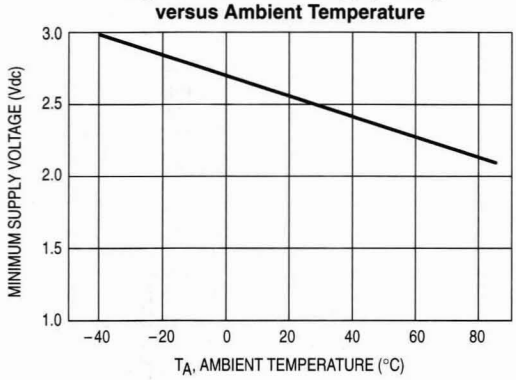



**Figure 23. RSSI Current versus Ambient Temperature and Signal Level**

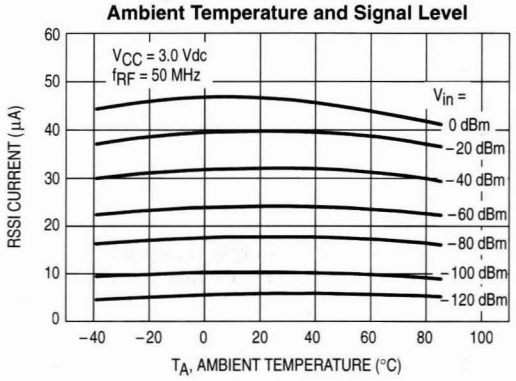



**Figure 24. Recovered Audio versus Ambient Temperature**

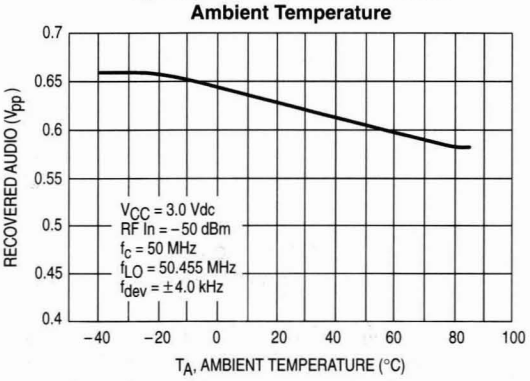



**Figure 25. Demod DC Output Voltage versus Ambient Temperature**

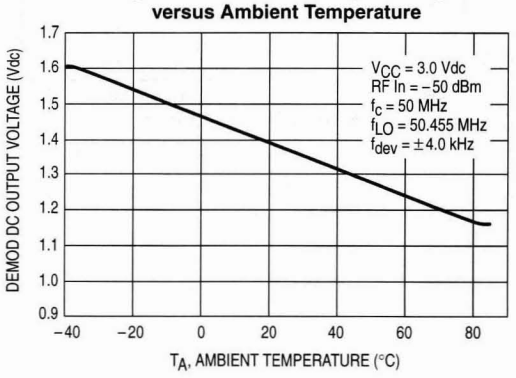



**Figure 26. LO Current versus Ambient Temperature**

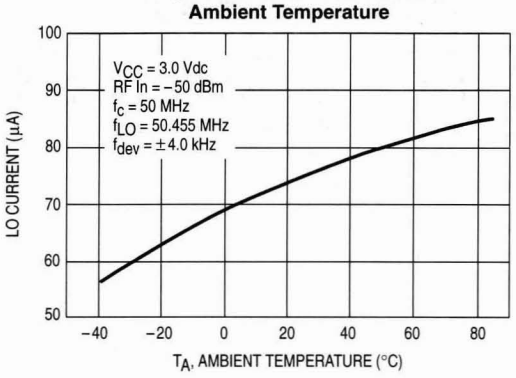


Figure 27. Component Placement View – Circuit Side

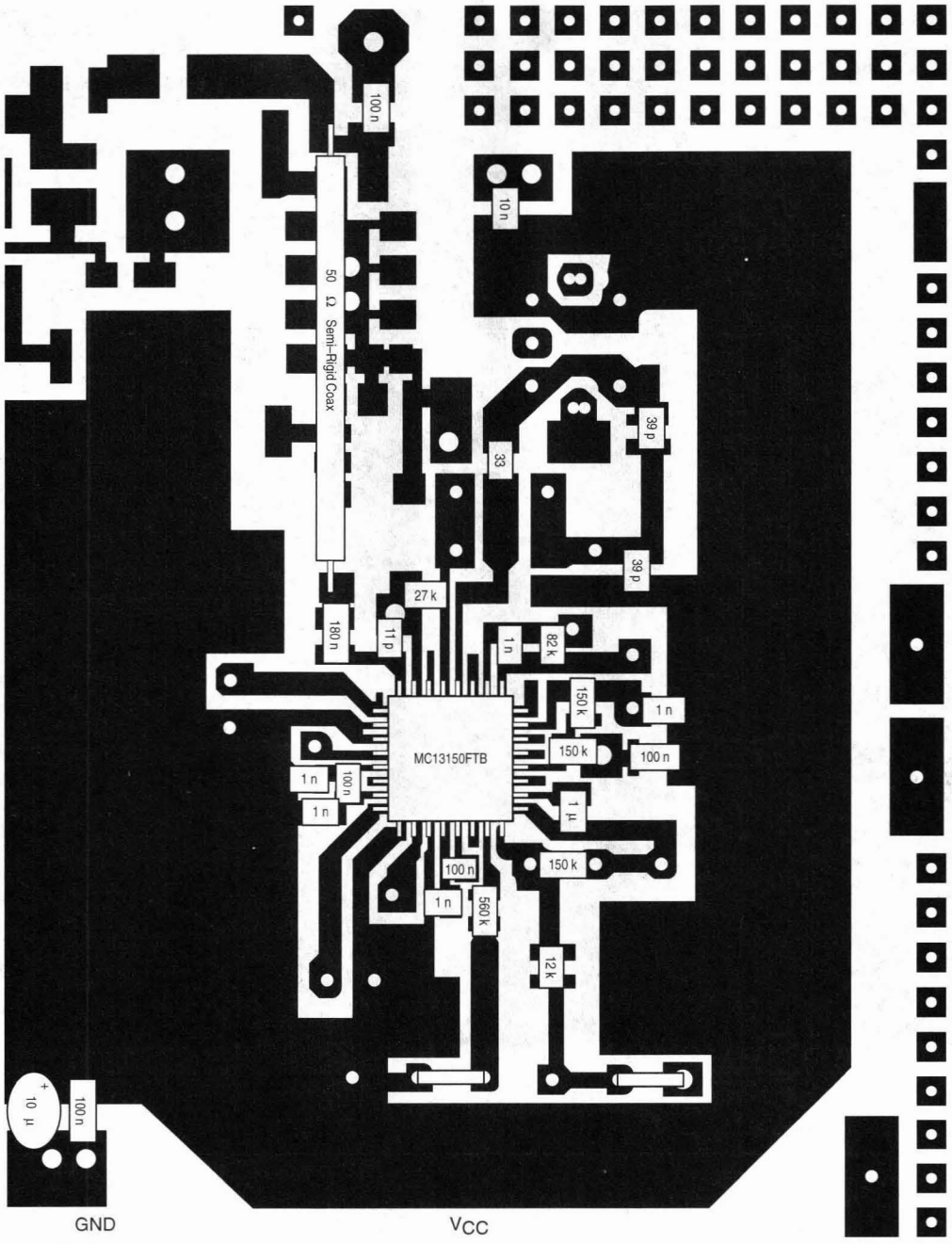


Figure 28. Component Placement View – Ground Side

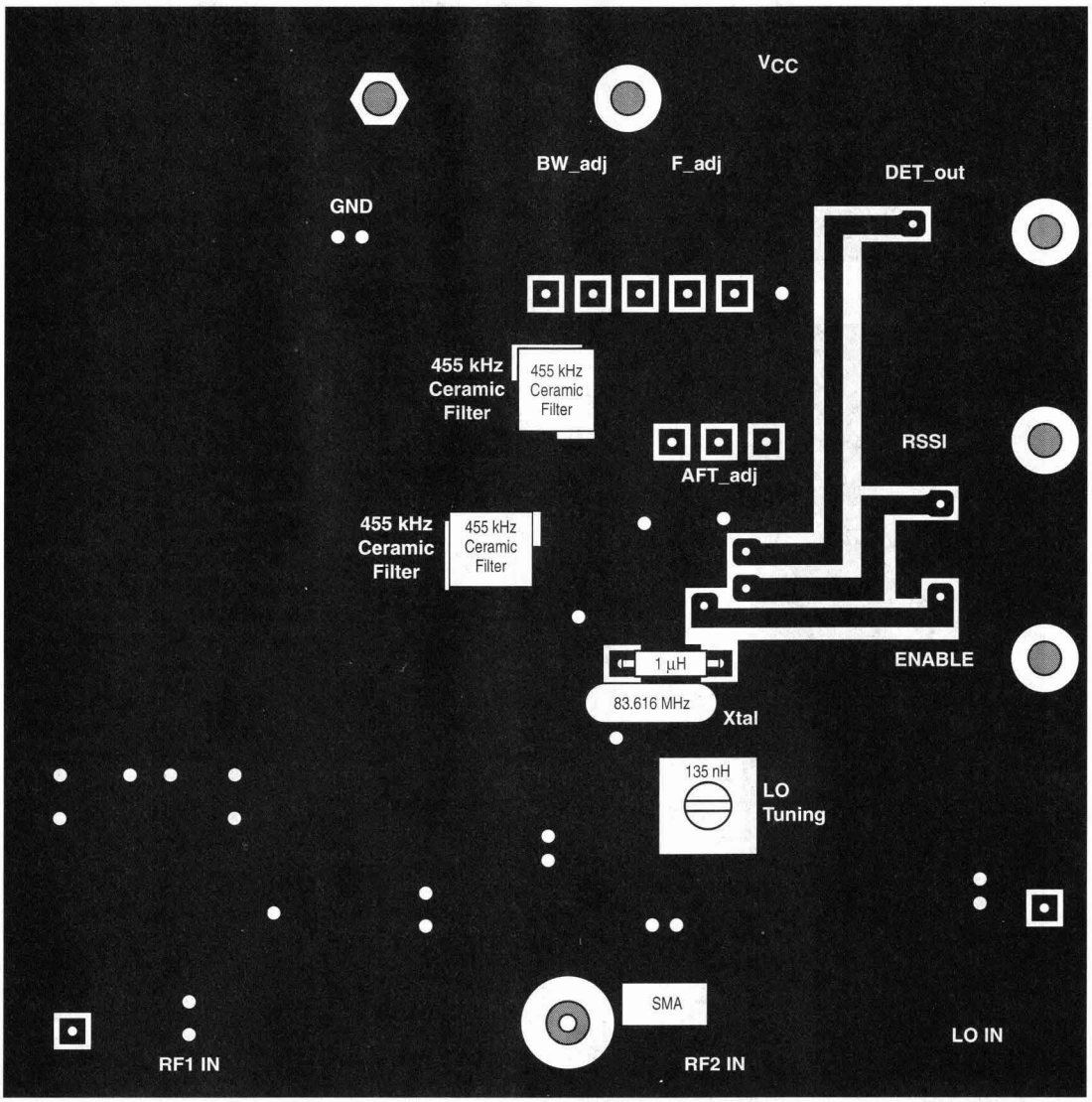


Figure 29. PCB Circuit Side View

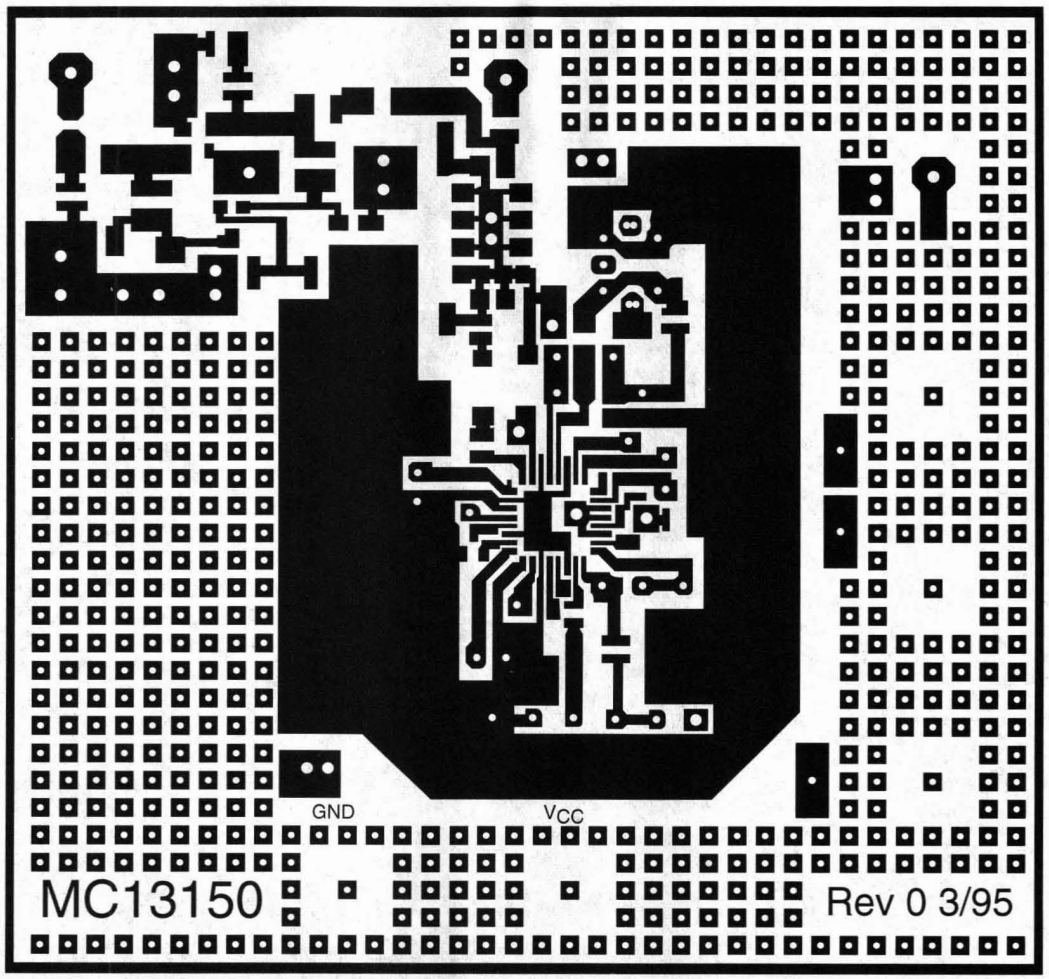
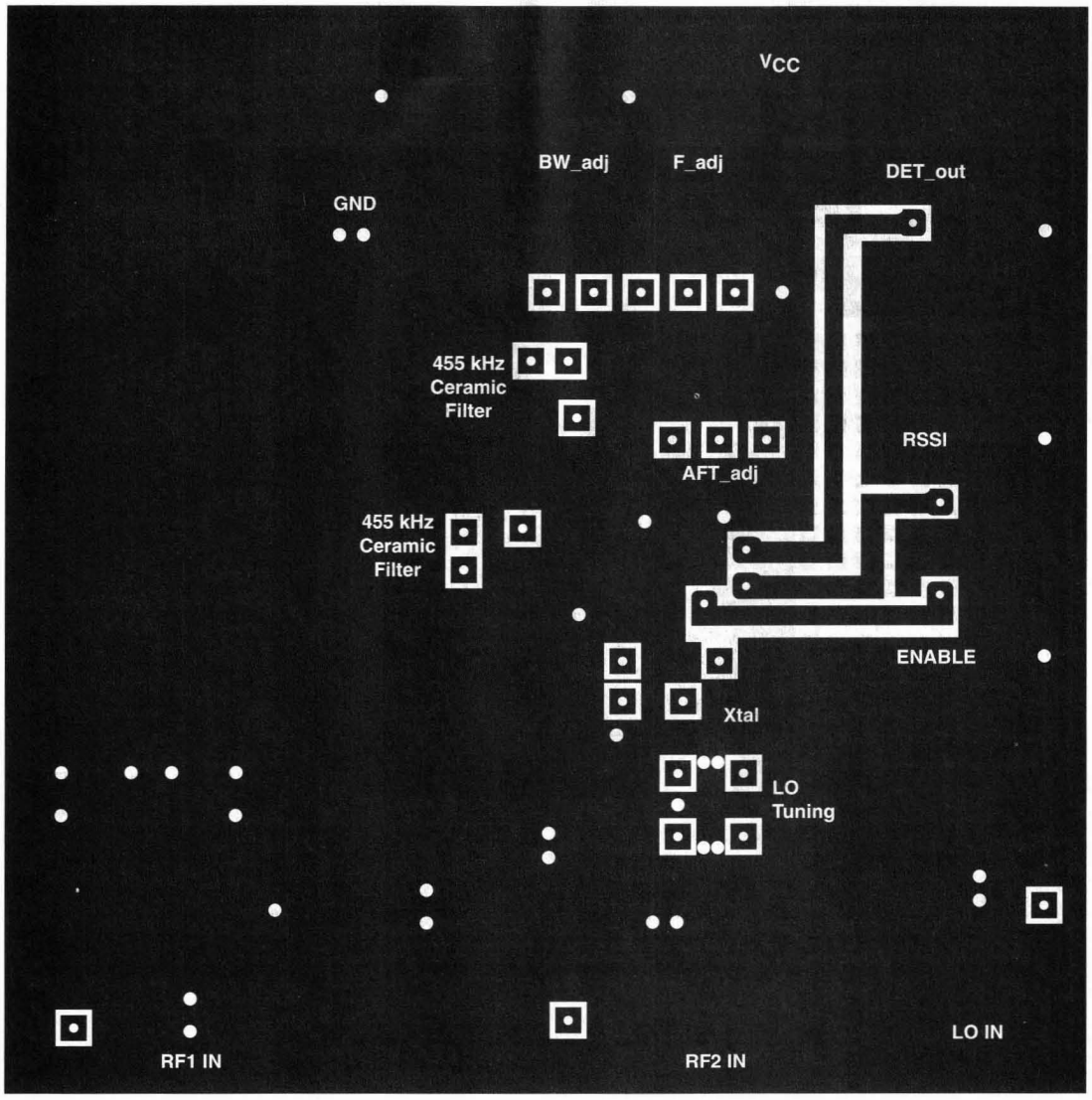


Figure 30. PCB Ground Side View



MOTOROLA

# MC13155

## Wideband FM IF

The MC13155 is a complete wideband FM detector designed for satellite TV and other wideband data and analog FM applications. This device may be cascaded for higher IF gain and extended Receive Signal Strength Indicator (RSSI) range.

- 12 MHz Video/Baseband Demodulator
- Ideal for Wideband Data and Analog FM Systems
- Limiter Output for Cascade Operation
- Low Drain Current: 7.0 mA
- Low Supply Voltage: 3.0 to 6.0 V
- Operates to 300 MHz

**WIDEBAND FM IF**

**SEMICONDUCTOR TECHNICAL DATA**

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

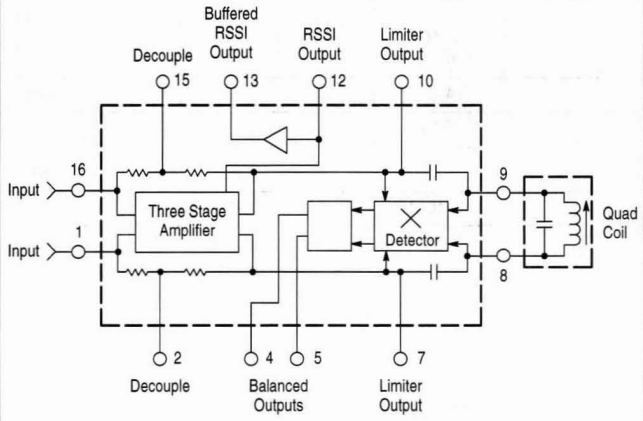
8

### MAXIMUM RATINGS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 11, 14 | $V_{EE}$ (max) | 6.5 | Vdc |
| Input Voltage | 1, 16 | $V_{in}$ | 1.0 | Vrms |
| Junction Temperature | – | $T_J$ | +150 | °C |
| Storage Temperature Range | – | $T_{stg}$ | – 65 to +150 | °C |

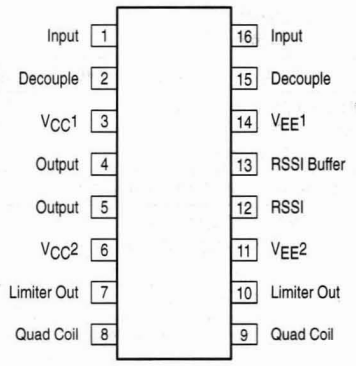
**NOTE:** Devices should not be operated at or outside these values. The "Recommended Operating Conditions" provide for actual device operation.

**Figure 1. Representative Block Diagram**




**NOTE:** This device requires careful layout and decoupling to ensure stable operation.

### PIN CONNECTIONS




(Top View)

### ORDERING INFORMATION

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13155D | $T_A$ = – 40 to +85°C | SO–16 |

## RECOMMENDED OPERATING CONDITIONS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage ($T_A$= 25°C)<br>– 40°C ≤ $T_A$ ≤ 85°C | 11, 14<br>3, 6 | $V_{EE}$<br>$V_{CC}$ | – 3.0 to – 6.0<br>Grounded | Vdc |
| Maximum Input Frequency | 1, 16 | $f_{in}$ | 300 | MHz |
| Ambient Temperature Range | – | $T_J$ | – 40 to + 85 | °C |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, no input signal.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Drain Current<br>($V_{EE}$ = – 5.0 Vdc)<br>($V_{EE}$ = – 5.0 Vdc) | 11<br>14<br>14 | $I_{11}$<br>$I_{14}$<br>$I_{14}$ | 2.0<br>3.0<br>3.0 | 2.8<br>4.3<br>4.3 | 4.0<br>6.0<br>6.0 | mA |
| Drain Current Total (see Figure 3)<br>($V_{EE}$ = – 5.0 Vdc)<br>($V_{EE}$ = – 6.0 Vdc)<br>($V_{EE}$ = – 3.0 Vdc) | 11, 14 | $I_{Total}$ | 5.0<br>5.0<br>5.0<br>4.7 | 7.1<br>7.5<br>7.5<br>6.6 | 10<br>10.5<br>10.5<br>9.5 | mA |

## AC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $f_{IF}$ = 70 MHz, $V_{EE}$ = – 5.0 Vdc Figure 2, unless otherwise noted.)

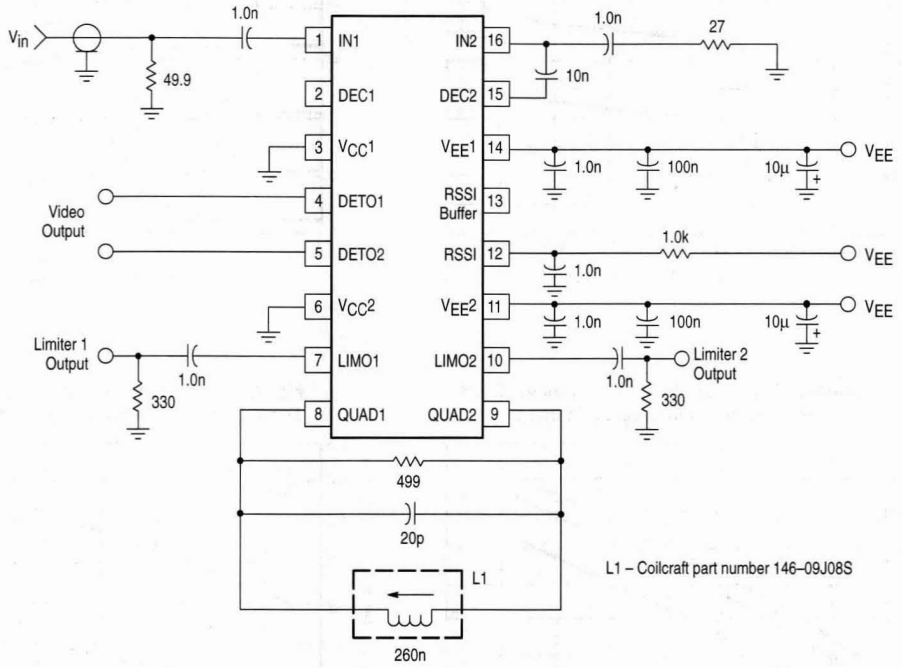
| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input for – 3 dB Limiting Sensitivity | 1, 16 | – | 1.0 | 2.0 | mVrms |
| Differential Detector Output Voltage ($V_{in}$ = 10 mVrms)<br>($f_{dev}$ = ± 3.0 MHz) ($V_{EE}$ = – 6.0 Vdc)<br>($V_{EE}$ = – 5.0 Vdc)<br>($V_{EE}$ = – 3.0 Vdc) | 4, 5 | <br>470<br>450<br>380 | <br>590<br>570<br>500 | <br>700<br>680<br>620 | $mV_{p-p}$ |
| Detector DC Offset Voltage | 4, 5 | – 250 | – | 250 | mVdc |
| RSSI Slope | 13 | 1.4 | 2.1 | 2.8 | µA/dB |
| RSSI Dynamic Range | 13 | 31 | 35 | 39 | dB |
| RSSI Output<br>($V_{in}$ = 100 µVrms)<br>($V_{in}$ = 1.0 mVrms)<br>($V_{in}$ = 10 mVrms)<br>($V_{in}$ = 100 mVrms)<br>($V_{in}$ = 500 mVrms) | 12 | <br>–<br>–<br>16<br>–<br>– | <br>2.1<br>2.4<br>24<br>65<br>75 | <br>–<br>–<br>36<br>–<br>– | µA |
| RSSI Buffer Maximum Output Current ($V_{in}$ = 10 mVrms) | 13 | – | 2.3 | – | mAdc |
| Differential Limiter Output<br>($V_{in}$ = 1.0 mVrms)<br>($V_{in}$ = 10 mVrms) | 7, 10 | <br>100<br>– | <br>140<br>180 | <br>–<br>– | mVrms |
| Demodulator Video 3.0 dB Bandwidth | 4, 5 | – | 12 | – | MHz |
| Input Impedance (Figure 14)<br>@ 70 MHz Rp ($V_{EE}$ = – 5.0 Vdc)<br>Cp ($C_2$=$C_{15}$ = 100 p) | 1, 16 | <br>–<br>– | <br>450<br>4.8 | <br>–<br>– | <br>Ω<br>pF |
| Differential IF Power Gain | 1, 7, 10, 16 | – | 46 | – | dB |

**NOTE**: Positive currents are out of the pins of the device.

## CIRCUIT DESCRIPTION

The MC13155 consists of a wideband three–stage limiting amplifier, a wideband quadrature detector which may be operated up to 200 MHz, and a received signal strength indicator (RSSI) circuit which provides a current output linearly proportional to the IF input signal level for approximately 35 dB range of input level.

**Figure 2. Test Circuit**




## APPLICATIONS INFORMATION

### Evaluation PC Board

The evaluation PCB shown in Figures 19 and 20 is very versatile and is designed to cascade two ICs. The center section of the board provides an area for attaching all surface mount components to the circuit side and radial leaded components to the component ground side of the PCB (see Figures 17 and 18). Additionally, the peripheral area surrounding the RF core provides pads to add supporting and interface circuitry as a particular application dictates. This evaluation board will be discussed and referenced in this section.

### Limiting Amplifier

Differential input and output ports interfacing the three stage limiting amplifier provide a differential power gain of typically 46 dB and useable frequency range of 300 MHz. The IF gain flatness may be controlled by decoupling of the internal feedback network at Pins 2 and 15.

Scattering parameter (S–parameter) characterization of the IF as a two port linear amplifier is useful to implement maximum stable power gain, input matching, and stability over a desired bandpass response and to ensure stable operation outside the bandpass as well. The MC13155 is unconditionally stable over most of its useful operating frequency range; however, it can be made unconditionally stable over its entire operating range with the proper decoupling of Pins 2 and 15. Relatively small decoupling capacitors of about 100 pF have a significant effect on the wideband response and stability. This is shown in the scattering parameter tables where S–parameters are shown for various values of C2 and C15 and at $V_{EE}$ of – 3.0 and – 5.0 Vdc.

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## TYPICAL PERFORMANCE AT TEMPERATURE
(See Figure 2. Test Circuit)

**Figure 3. Drain Current versus Supply Voltage**

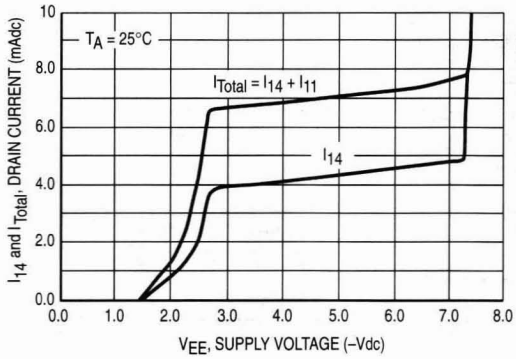



**Figure 4. RSSI Output versus Frequency and Input Signal Level**

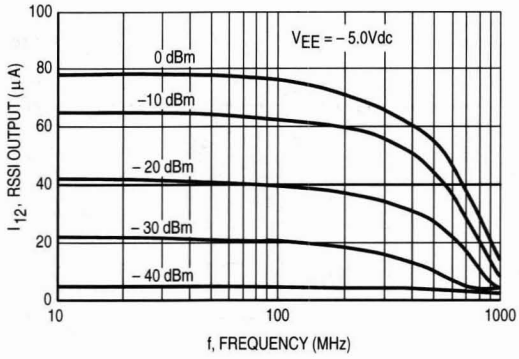



**Figure 5. Total Drain Current versus Ambient Temperature and Supply Voltage**

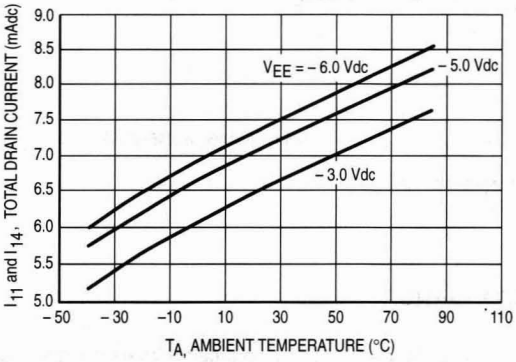



**Figure 6. Detector Drain Current and Limiter Drain Current versus Ambient Temperature**

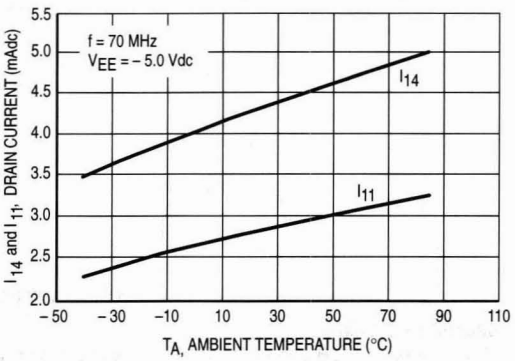



**Figure 7. RSSI Output versus Ambient Temperature and Supply Voltage**

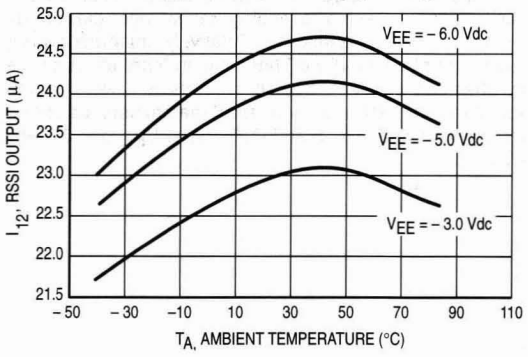



**Figure 8. RSSI Output versus Input Signal Voltage** ($V_{in}$ at Temperature)

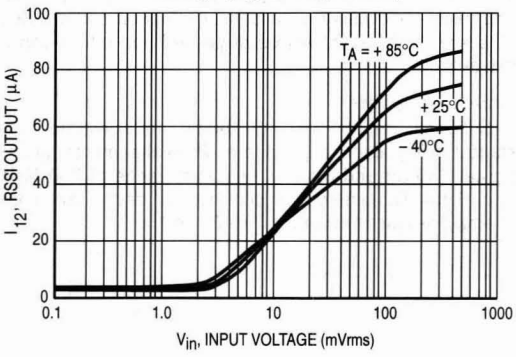


**Figure 9. Differential Detector Output Voltage versus Ambient Temperature and Supply Voltage**

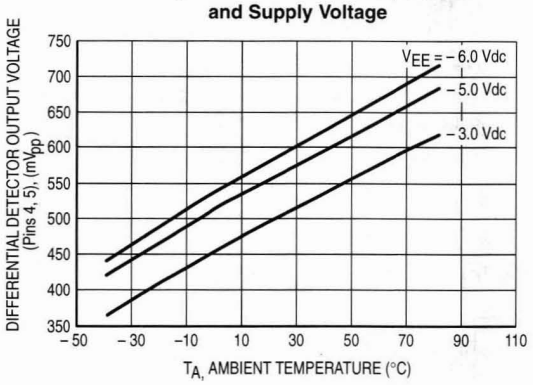



**Figure 10. Differential Limiter Output Voltage versus Ambient Temperature**
($V_{in}$ = 1 and 10 mVrms)

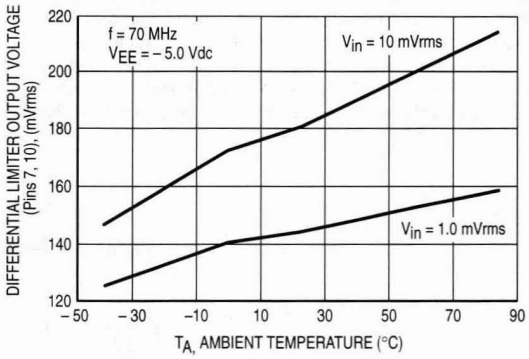



**Figure 11A. Differential Detector Output Voltage versus Q of Quadrature LC Tank**

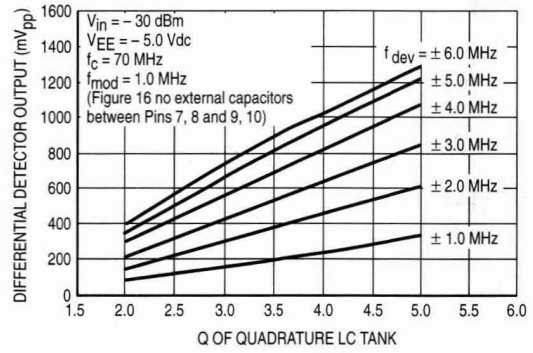



**Figure 11B. Differential Detector Output Voltage versus Q of Quadrature LC Tank**

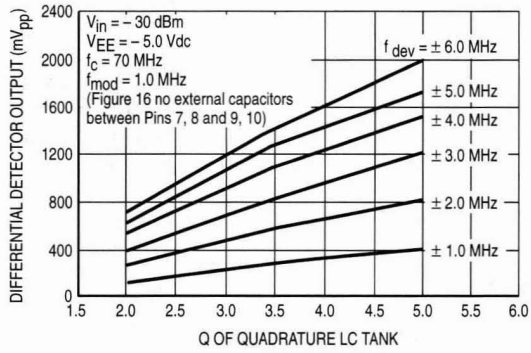



**Figure 12. RSSI Output Voltage versus IF Input**

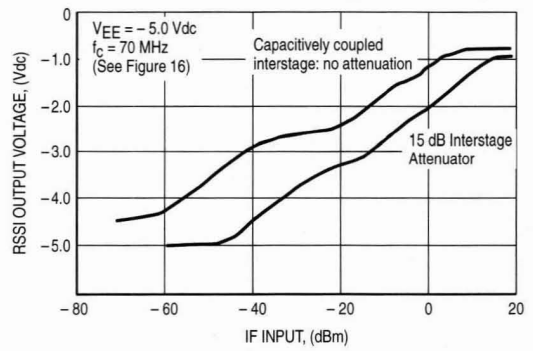
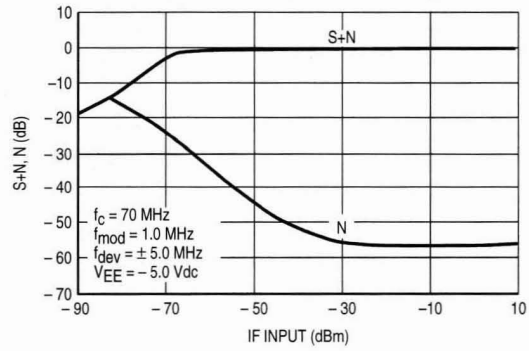



**Figure 13. – S+N, N versus IF Input**

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In the S–parameters measurements, the IF is treated as a two–port linear class A amplifier. The IF amplifier is measured with a single–ended input and output configuration in which the Pins 16 and 7 are terminated in the series combination of a 47 Ω resistor and a 10 nF capacitor to $V_{CC}$ ground (see Figure 14. S–Parameter Test Circuit).

The S–parameters are in polar form as the magnitude (MAG) and angle (ANG). Also listed in the tables are the calculated values for the stability factor (K) and the Maximum Available Gain (MAG). These terms are related in the following equations:

$$K = (1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2) / (2 |S_{12} S_{21}|)$$

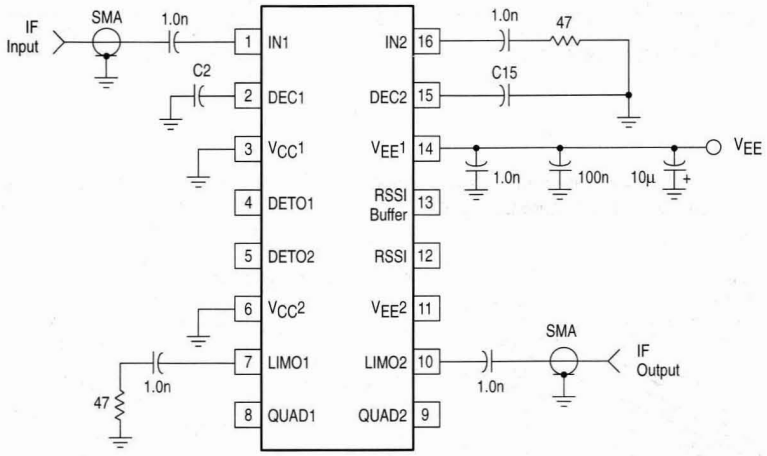
where: $|\Delta| = |S_{11} S_{22} - S_{12} S_{21}|$.

$$MAG = 10 \log |S_{21}| / |S_{12}| + 10 \log |K - (K^2 - 1)^{1/2}|$$

where: K > 1. The necessary and sufficient conditions for unconditional stability are given as K > 1:

$$B1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 > 0$$

**Figure 14. S–Parameter Test Circuit**



**S–Parameters** ($V_{EE}$ = – 5.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 0 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.94 | –13 | 8.2 | 143 | 0.001 | 7.0 | 0.87 | – 22 | 2.2 | 32 |
| 2.0 | 0.78 | – 23 | 23.5 | 109 | 0.001 | – 40 | 0.64 | – 31 | 4.2 | 33.5 |
| 5.0 | 0.48 | 1.0 | 39.2 | 51 | 0.001 | – 97 | 0.34 | –17 | 8.7 | 33.7 |
| 7.0 | 0.59 | 15 | 40.3 | 34 | 0.001 | – 41 | 0.33 | –13 | 10.6 | 34.6 |
| 10 | 0.75 | 17 | 40.9 | 19 | 0.001 | – 82 | 0.41 | –1.0 | 5.7 | 36.7 |
| 20 | 0.95 | 7.0 | 42.9 | – 6.0 | 0.001 | – 42 | 0.45 | 0 | 1.05 | 46.4 |
| 50 | 0.98 | –10 | 42.2 | – 48 | 0.001 | – 9.0 | 0.52 | – 3.0 | 0.29 | – |
| 70 | 0.95 | –16 | 39.8 | – 68 | 0.001 | 112 | 0.54 | –16 | 1.05 | 46.4 |
| 100 | 0.93 | – 23 | 44.2 | – 93 | 0.001 | 80 | 0.53 | – 22 | 0.76 | – |
| 150 | 0.91 | – 34 | 39.5 | –139 | 0.001 | 106 | 0.50 | – 34 | 0.94 | – |
| 200 | 0.87 | – 47 | 34.9 | –179 | 0.002 | 77 | 0.42 | – 44 | 0.97 | – |
| 500 | 0.89 | –103 | 11.1 | – 58 | 0.022 | 57 | 0.40 | –117 | 0.75 | – |
| 700 | 0.61 | –156 | 3.5 | –164 | 0.03 | 0 | 0.52 | 179 | 2.6 | 13.7 |
| 900 | 0.56 | 162 | 1.2 | 92 | 0.048 | – 44 | 0.47 | 112 | 4.7 | 4.5 |
| 1000 | 0.54 | 131 | 0.8 | 42 | 0.072 | – 48 | 0.44 | 76 | 5.1 | 0.4 |

**S–Parameters** ($V_{EE}$ = – 5.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 100 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.98 | –15 | 11.7 | 174 | 0.001 | –14 | 0.84 | – 27 | 1.2 | 37.4 |
| 2.0 | 0.50 | – 2.0 | 39.2 | 85.5 | 0.001 | –108 | 0.62 | – 35 | 6.0 | 35.5 |
| 5.0 | 0.87 | 8.0 | 39.9 | 19 | 0.001 | 100 | 0.47 | – 9.0 | 4.2 | 39.2 |
| 7.0 | 0.90 | 5.0 | 40.4 | 9.0 | 0.001 | – 40 | 0.45 | – 8.0 | 3.1 | 40.3 |
| 10 | 0.92 | 3.0 | 41 | 1.0 | 0.001 | – 40 | 0.44 | – 5.0 | 2.4 | 41.8 |
| 20 | 0.92 | – 2.0 | 42.4 | –14 | 0.001 | – 87 | 0.49 | – 6.0 | 2.4 | 41.9 |
| 50 | 0.91 | – 8.0 | 41.2 | – 45 | 0.001 | 85 | 0.50 | – 5.0 | 2.3 | 42 |
| 70 | 0.91 | –11 | 39.1 | – 63 | 0.001 | 76 | 0.52 | – 4.0 | 2.2 | 41.6 |
| 100 | 0.91 | –15 | 43.4 | – 84 | 0.001 | 85 | 0.50 | –11 | 1.3 | 43.6 |
| 150 | 0.90 | – 22 | 38.2 | –126 | 0.001 | 96 | 0.43 | – 22 | 1.4 | 41.8 |
| 200 | 0.86 | – 33 | 35.5 | –160 | 0.002 | 78 | 0.43 | – 21 | 1.3 | 39.4 |
| 500 | 0.80 | – 66 | 8.3 | – 9.0 | 0.012 | 75 | 0.57 | – 63 | 1.7 | 23.5 |
| 700 | 0.62 | – 96 | 2.9 | – 95 | 0.013 | 50 | 0.49 | –111 | 6.3 | 12.5 |
| 900 | 0.56 | –120 | 1.0 | –171 | 0.020 | 53 | 0.44 | –150 | 13.3 | 2.8 |
| 1000 | 0.54 | –136 | 0.69 | 154 | 0.034 | 65 | 0.44 | –179 | 12.5 | – 0.8 |

**S–Parameters** ($V_{EE}$ = – 5.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 680 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.74 | 4.0 | 53.6 | 110 | 0.001 | 101 | 0.97 | – 35 | 0.58 | – |
| 2.0 | 0.90 | 3.0 | 70.8 | 55 | 0.001 | 60 | 0.68 | – 34 | 1.4 | 45.6 |
| 5.0 | 0.91 | 0 | 87.1 | 21 | 0.001 | –121 | 0.33 | – 60 | 1.1 | 49 |
| 7.0 | 0.91 | 0 | 90.3 | 11 | 0.001 | –18 | 0.25 | – 67 | 1.2 | 48.4 |
| 10 | 0.91 | – 2.0 | 92.4 | 2.0 | 0.001 | 33 | 0.14 | – 67 | 1.5 | 47.5 |
| 20 | 0.91 | – 4.0 | 95.5 | –16 | 0.001 | 63 | 0.12 | –15 | 1.3 | 48.2 |
| 50 | 0.90 | – 8.0 | 89.7 | – 50 | 0.001 | – 43 | 0.24 | 26 | 1.8 | 46.5 |
| 70 | 0.90 | –10 | 82.6 | –70 | 0.001 | 92 | 0.33 | 21 | 1.4 | 47.4 |
| 100 | 0.91 | –14 | 77.12 | –93 | 0.001 | 23 | 0.42 | –1.0 | 1.05 | 49 |
| 150 | 0.94 | – 20 | 62.0 | –122 | 0.001 | 96 | 0.42 | – 22 | 0.54 | – |
| 200 | 0.95 | – 33 | 56.9 | –148 | 0.003 | 146 | 0.33 | – 62 | 0.75 | – |
| 500 | 0.82 | – 63 | 12.3 | –12 | 0.007 | 79 | 0.44 | – 67 | 1.8 | 26.9 |
| 700 | 0.66 | – 98 | 3.8 | –107 | 0.014 | 84 | 0.40 | –115 | 4.8 | 14.6 |
| 900 | 0.56 | –122 | 1.3 | 177 | 0.028 | 78 | 0.39 | –166 | 8.0 | 4.7 |
| 1000 | 0.54 | –139 | 0.87 | 141 | 0.048 | 76 | 0.41 | 165 | 7.4 | 0.96 |

**S–Parameters** ($V_{EE}$ = – 3.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 0 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.89 | –14 | 9.3 | 136 | 0.001 | 2.0 | 0.84 | – 27 | 3.2 | 30.7 |
| 2.0 | 0.76 | – 22 | 24.2 | 105 | 0.001 | – 90 | 0.67 | – 37 | 3.5 | 34.3 |
| 5.0 | 0.52 | 5.0 | 35.7 | 46 | 0.001 | – 32 | 0.40 | –13 | 10.6 | 33.3 |
| 7.0 | 0.59 | 12 | 38.1 | 34 | 0.001 | – 41 | 0.40 | –10 | 9.1 | 34.6 |
| 10 | 0.78 | 15 | 37.2 | 16 | 0.001 | – 92 | 0.40 | –1.0 | 5.7 | 36.3 |
| 20 | 0.95 | 5.0 | 38.2 | – 9.0 | 0.001 | 47 | 0.51 | – 4.0 | 0.94 | – |
| 50 | 0.96 | –11 | 39.1 | – 50 | 0.001 | –103 | 0.48 | – 6.0 | 1.4 | 43.7 |
| 70 | 0.93 | –17 | 36.8 | – 71 | 0.001 | – 76 | 0.52 | –13 | 2.2 | 41.4 |
| 100 | 0.91 | – 25 | 34.7 | – 99 | 0.001 | –152 | 0.51 | –19 | 3.0 | 39.0 |
| 150 | 0.86 | – 37 | 33.8 | –143 | 0.001 | 53 | 0.49 | – 34 | 1.7 | 39.1 |
| 200 | 0.81 | – 49 | 27.8 | 86 | 0.003 | 76 | 0.55 | – 56 | 2.4 | 35.1 |
| 500 | 0.70 | – 93 | 6.2 | – 41 | 0.015 | 93 | 0.40 | –110 | 2.4 | 19.5 |
| 700 | 0.62 | –144 | 1.9 | –133 | 0.049 | 56 | 0.40 | –150 | 3.0 | 8.25 |
| 900 | 0.39 | –176 | 0.72 | 125 | 0.11 | –18 | 0.25 | 163 | 5.1 | –1.9 |
| 1000 | 0.44 | 166 | 0.49 | 80 | 0.10 | – 52 | 0.33 | 127 | 7.5 | – 4.8 |

**S–Parameters** ($V_{EE}$ = – 3.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 100 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.97 | –15 | 11.7 | 171 | 0.001 | – 4.0 | 0.84 | – 27 | 1.4 | 36.8 |
| 2.0 | 0.53 | 2.0 | 37.1 | 80 | 0.001 | – 91 | 0.57 | – 31 | 6.0 | 34.8 |
| 5.0 | 0.88 | 7.0 | 37.7 | 18 | 0.001 | – 9.0 | 0.48 | – 7.0 | 3.4 | 39.7 |
| 7.0 | 0.90 | 5.0 | 37.7 | 8.0 | 0.001 | –11 | 0.49 | – 7.0 | 2.3 | 41 |
| 10 | 0.92 | 2.0 | 38.3 | 1.0 | 0.001 | – 59 | 0.51 | – 9.0 | 2.0 | 41.8 |
| 20 | 0.92 | – 2.0 | 39.6 | –15 | 0.001 | 29 | 0.48 | – 3.0 | 1.9 | 42.5 |
| 50 | 0.91 | – 8.0 | 38.5 | – 46 | 0.001 | – 21 | 0.51 | – 7.0 | 2.3 | 41.4 |
| 70 | 0.91 | –11 | 36.1 | – 64 | 0.001 | 49 | 0.50 | – 8.0 | 2.3 | 40.8 |
| 100 | 0.91 | –15 | 39.6 | – 85 | 0.001 | 114 | 0.52 | –13 | 1.7 | 37.8 |
| 150 | 0.89 | – 22 | 34.4 | –128 | 0.001 | 120 | 0.48 | – 23 | 1.6 | 40.1 |
| 200 | 0.86 | – 33 | 32 | –163 | 0.002 | 86 | 0.40 | – 26 | 1.7 | 37.8 |
| 500 | 0.78 | – 64 | 7.6 | –12 | 0.013 | 94 | 0.46 | – 71 | 1.9 | 22.1 |
| 700 | 0.64 | – 98 | 2.3 | –102 | 0.027 | 58 | 0.42 | –109 | 4.1 | 10.1 |
| 900 | 0.54 | –122 | 0.78 | 179 | 0.040 | 38.6 | 0.35 | –147 | 10.0 | – 0.14 |
| 1000 | 0.53 | –136 | 0.47 | 144 | 0.043 | 23 | 0.38 | –171 | 15.4 | – 4.52 |

**S–Parameters** ($V_{EE}$ = – 3.0 Vdc, $T_A$ = 25°C, $C_2$ and $C_{15}$ = 680 pF)

| Frequency | Input S11 | | Forward S21 | | Rev S12 | | Output S22 | | K | MAG |
|---|---|---|---|---|---|---|---|---|---|---|
| MHz | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | MAG | dB |
| 1.0 | 0.81 | 3.0 | 37 | 101 | 0.001 | –19 | 0.90 | – 32 | 1.1 | 43.5 |
| 2.0 | 0.90 | 2.0 | 47.8 | 52.7 | 0.001 | – 82 | 0.66 | – 39 | 0.72 | – |
| 5.0 | 0.91 | 0 | 58.9 | 20 | 0.001 | 104 | 0.37 | – 56 | 2.3 | 44 |
| 7.0 | 0.90 | –1 | 60.3 | 11 | 0.001 | – 76 | 0.26 | – 55 | 2.04 | 44 |
| 10 | 0.91 | – 2.0 | 61.8 | 3.0 | 0.001 | 105 | 0.18 | – 52 | 2.2 | 43.9 |
| 20 | 0.91 | – 4.0 | 63.8 | – 15 | 0.001 | 59 | 0.11 | –13 | 2.0 | 44.1 |
| 50 | 0.90 | – 8.0 | 60.0 | – 48 | 0.001 | 96 | 0.22 | 33 | 2.3 | 43.7 |
| 70 | 0.90 | –11 | 56.5 | – 67 | 0.001 | 113 | 0.29 | 15 | 2.3 | 43.2 |
| 100 | 0.91 | –14 | 52.7 | – 91 | 0.001 | 177 | 0.36 | 5.0 | 2.0 | 43 |
| 150 | 0.93 | – 21 | 44.5 | –126 | 0.001 | 155 | 0.35 | –17 | 1.8 | 42.7 |
| 200 | 0.90 | – 43 | 41.2 | –162 | 0.003 | 144 | 0.17 | – 31 | 1.6 | 34.1 |
| 500 | 0.79 | – 65 | 7.3 | –13 | 0.008 | 80 | 0.44 | – 75 | 3.0 | 22 |
| 700 | 0.65 | – 97 | 2.3 | –107 | 0.016 | 86 | 0.38 | –124 | 7.1 | 10.2 |
| 900 | 0.56 | –122 | 0.80 | 174 | 0.031 | 73 | 0.38 | –174 | 12 | 0.37 |
| 1000 | 0.55 | –139 | 0.52 | 137 | 0.50 | 71 | 0.41 | 157 | 11.3 | – 3.4 |

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### DC Biasing Considerations

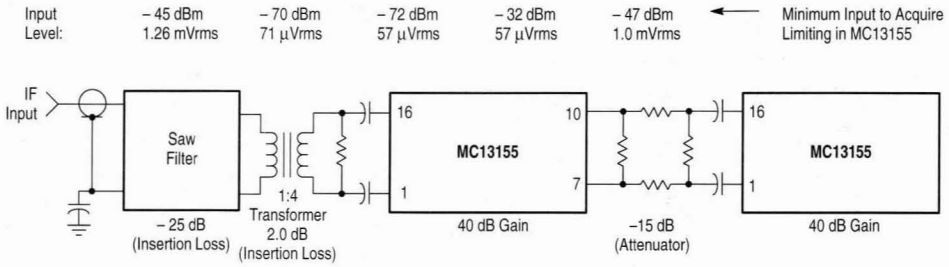
The DC biasing scheme utilizes two $V_{CC}$ connections (Pins 3 and 6) and two $V_{EE}$ connections (Pins 14 and 11). $V_{EE}1$ (Pin 14) is connected internally to the IF and RSSI circuits' negative supply bus while $V_{EE}2$ (Pin 11) is connected internally to the quadrature detector's negative bus. Under positive ground operation, this unique configuration offers the ability to bias the RSSI and IF separately from the quadrature detector. When two ICs are cascaded as shown in the 70 MHz application circuit and provided by the PCB (see Figures 17 and 18), the first MC13155 is used without biasing its quadrature detector, thereby saving approximately 3.0 mA. A total current of 7.0 mA is used to fully bias each IC, thus the total current in the application circuit is approximately 11 mA. Both $V_{CC}$ pins are biased by the same supply. $V_{CC}1$ (Pin 3) is connected internally to the positive bus of the first half of the IF limiting amplifier, while $V_{CC}2$ is internally connected to the positive bus of the RSSI, the quadrature detector circuit, and the second half of the IF limiting amplifier (see Figure 15). This distribution of the $V_{CC}$ enhances the stability of the IC.

### RSSI Circuitry

The RSSI circuitry provides typically 35 dB of linear dynamic range and its output voltage swing is adjusted by selection of the resistor from Pin 12 to $V_{EE}$. The RSSI slope is typically 2.1 μA/dB ; thus, for a dynamic range of 35 dB, the current output is approximately 74 μA. A 47 k resistor will yield an RSSI output voltage swing of 3.5 Vdc. The RSSI buffer output at Pin 13 is an emitter–follower and needs an external emitter resistor of 10 k to $V_{EE}$.

In a cascaded configuration (see circuit application in Figure 16), only one of the RSSI Buffer outputs (Pin 13) is used; the RSSI outputs (Pin 12 of each IC) are tied together and the one closest to the $V_{EE}$ supply trace is decoupled to $V_{CC}$ ground. The two pins are connected to $V_{EE}$ through a 47 k resistor. This resistor sources a RSSI current which is proportional to the signal level at the IF input; typically, 1.0 mVrms (– 47 dBm) is required to place the MC13155 into limiting. The measured RSSI output voltage response of the application circuit is shown in Figure 12. Since the RSSI current output is dependent upon the input signal level at the IF input, a careful accounting of filter losses, matching and other losses and gains must be made in the entire receiver system. In the block diagram of the application circuit shown below, an accounting of the signal levels at points throughout the system shows how the RSSI response in Figure 12 is justified.

**Block Diagram of 70 MHz Video Receiver Application Circuit**

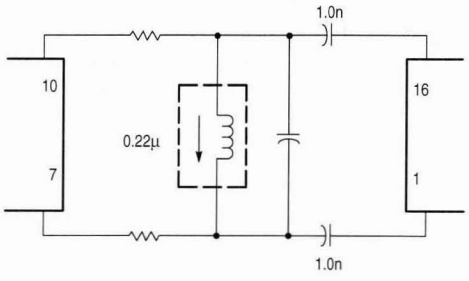



### Cascading Stages

The limiting IF output is pinned–out differentially, cascading is easily achieved by AC coupling stage to stage. In the evaluation PCB, AC coupling is shown, however, interstage filtering may be desirable in some applications. In which case, the S–parameters provide a means to implement a low loss interstage match and better receiver sensitivity.

Where a linear response of the RSSI output is desired when cascading the ICs, it is necessary to provide at least 10 dB of interstage loss. Figure 12 shows the RSSI response with and without interstage loss. A 15 dB resistive attenuator is an inexpensive way to linearize the RSSI response. This has its drawbacks since it is a wideband noise source that is dependent upon the source and load impedance and the amount of attenuation that it provides. A better, although more costly, solution would be a bandpass filter designed to the desired center frequency and bandpass response while carefully selecting the insertion loss. A network topology shown below may be used to provide a bandpass response with the desired insertion loss.

**Network Topology**



**Quadrature Detector**

The quadrature detector is coupled to the IF with internal 2.0 pF capacitors between Pins 7 and 8 and Pins 9 and 10. For wideband data applications, such as FM video and satellite receivers, the drive to the detector can be increased with additional external capacitors between these pins, thus, the recovered video signal level output is increased for a given bandwidth (see Figure 11A and Figure 11B).

The wideband performance of the detector is controlled by the loaded Q of the LC tank circuit. The following equation defines the components which set the detector circuit's bandwidth:

$$Q = R_T/X_L \quad (1)$$

where: $R_T$ is the equivalent shunt resistance across the LC Tank and $X_L$ is the reactance of the quadrature inductor at the IF frequency ($X_L = 2\pi fL$).

The inductor and capacitor are chosen to form a resonant LC Tank with the PCB and parasitic device capacitance at the desired IF center frequency as predicted by:

$$fc = (2\pi \sqrt{(LC_p)})^{-1} \quad (2)$$

where: L is the parallel tank inductor and $C_p$ is the equivalent parallel capacitance of the parallel resonant tank circuit.

The following is a design example for a wideband detector at 70 MHz and a loaded Q of 5. The loaded Q of the quadrature detector is chosen somewhat less than the Q of the IF bandpass. For an IF frequency of 70 MHz and an IF bandpass of 10.9 MHz, the IF bandpass Q is approximately 6.4.

Example:

Let the external Cext = 20 pF. (The minimum value here should be greater than 15 pF making it greater than the internal device and PCB parasitic capacitance, Cint ≈ 3.0 pF).

$$C_p = Cint + Cext = 23\ pF$$

Rewrite Equation 2 and solve for L:

$L = (0.159)^2/(C_p\ fc^2)$

L = 198 nH, thus, a standard value is chosen.

L = 0.22 μH (tunable shielded inductor).

The value of the total damping resistor to obtain the required loaded Q of 5 can be calculated by rearranging Equation 1:

$$R_T = Q(2\pi fL)$$

$R_T = 5\ (2\pi)(70)(0.22) = 483.8\ \Omega.$

The internal resistance, Rint between the quadrature tank Pins 8 and 9 is approximately 3200 Ω and is considered in determining the external resistance, Rext which is calculated from:

Rext = $((R_T)(Rint))/(Rint - R_T)$

Rext = 570, thus, choose the standard value.

Rext = 560 Ω.

**SAW Filter**

In wideband video data applications, the IF occupied bandwidth may be several MHz wide. A good rule of thumb is to choose the IF frequency about 10 or more times greater than the IF occupied bandwidth. The IF bandpass filter is a SAW filter in video data applications where a very selective response is needed (i.e., very sharp bandpass response). The evaluation PCB is laid out to accommodate two SAW filter package types: 1) A five–leaded plastic SIP package. Recommended part numbers are Siemens X6950M which operates at 70 MHz; 10.4 MHz 3 dB passband, X6951M (X252.8) which operates at 70 MHz; 9.2 MHz 3 dB passband; and X6958M which operates at 70 MHz, 6.3 MHz 3 dB passband, and 2) A four–leaded TO–39 metal can package. Typical insertion loss in a wide bandpass SAW filter is 25 dB.

The above SAW filters require source and load impedances of 50 Ω to assure stable operation. On the PC board layout, space is provided to add a matching network, such as a 1:4 surface mount transformer between the SAW filter output and the input to the MC13155. A 1:4 transformer, made by Coilcraft and Mini Circuits, provides a suitable interface (see Figures 16, 17 and 18). In the circuit and layout, the SAW filter and the MC13155 are differentially configured with interconnect traces which are equal in length and symmetrical. This balanced feed enhances RF stability, phase linearity, and noise performance.

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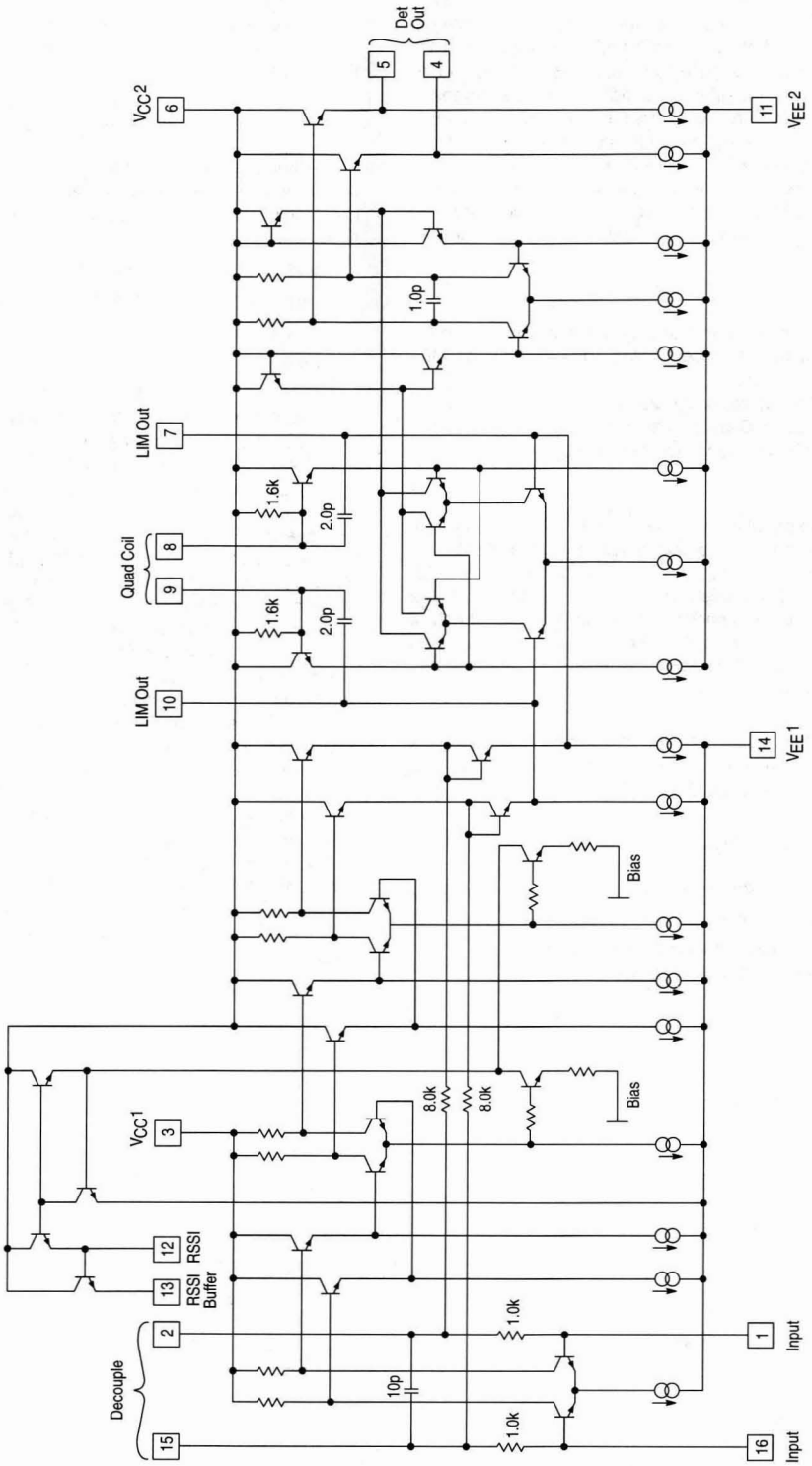


Figure 15. Simplified Internal Circuit Schematic

**Figure 16. 70 MHz Video Receiver Application Circuit**

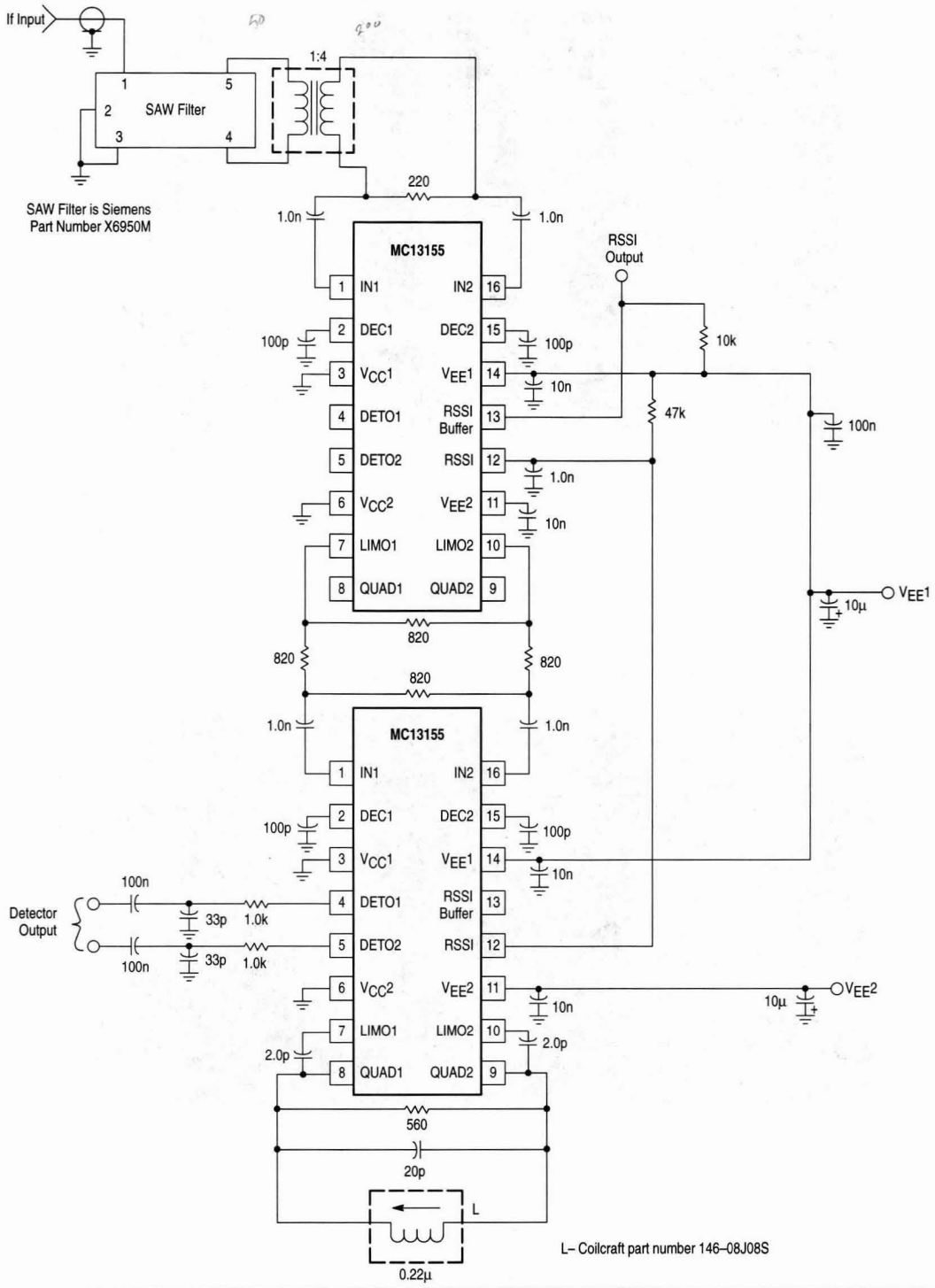


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Figure 17. Component Placement (Circuit Side)

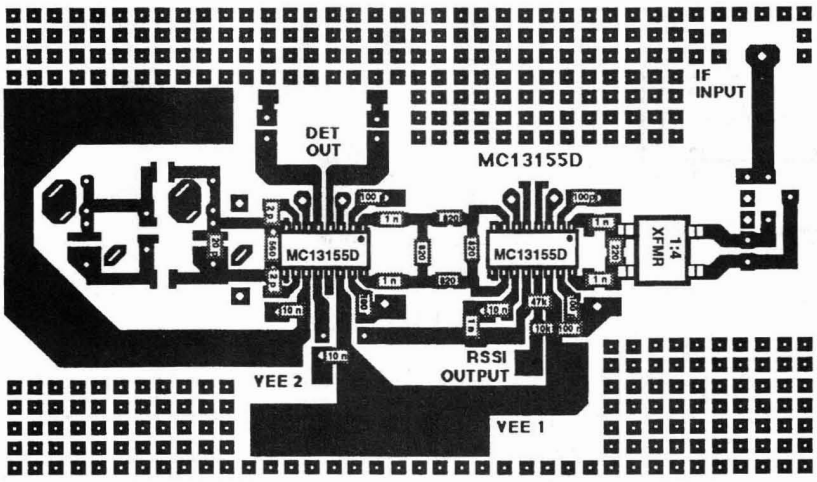


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Figure 18. Component Placement (Ground Side)

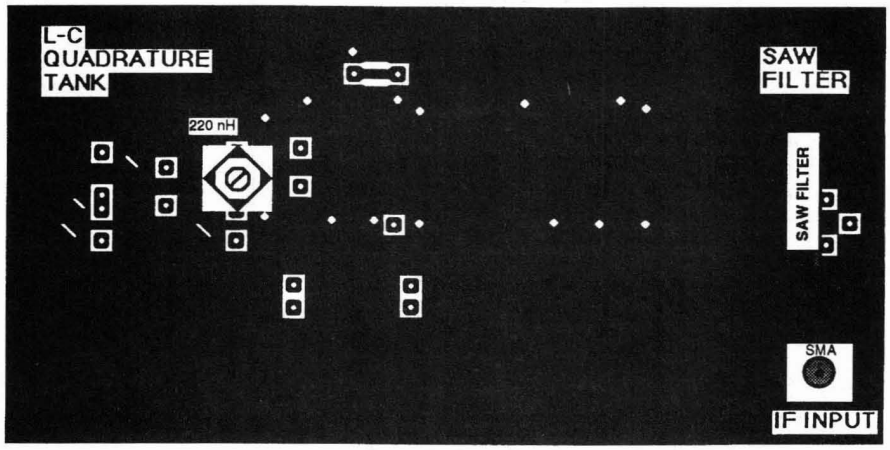


Figure 19. Circuit Side View

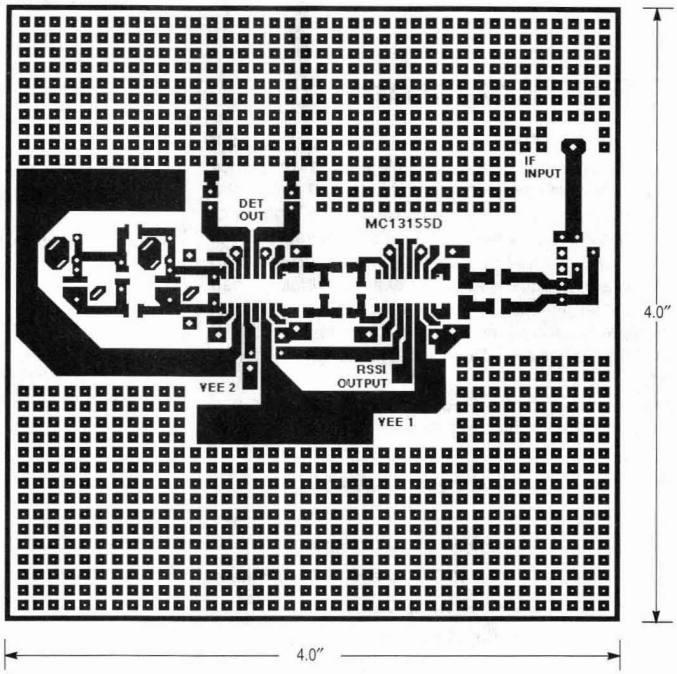
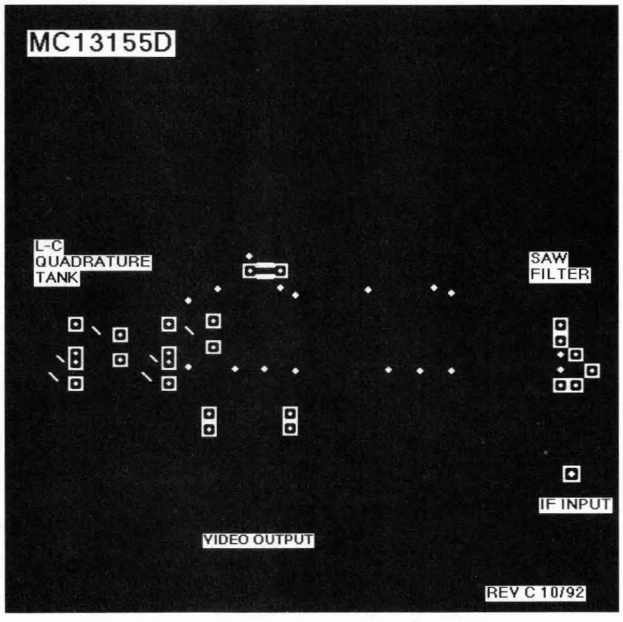





Figure 20. Ground Side View



MOTOROLA

# MC13156

## Wideband FM IF System

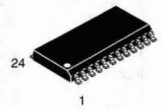
**WIDEBAND FM IF SYSTEM FOR DIGITAL AND ANALOG APPLICATIONS**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13156 is a wideband FM IF subsystem targeted at high performance data and analog applications. Excellent high frequency performance is achieved at low cost using Motorola's MOSAIC 1.5™ bipolar process. The MC13156 has an onboard grounded collector VCO transistor that may be used with a fundamental or overtone crystal in single channel operation or with a PLL in multichannel operation. The mixer is useful to 500 MHz and may be used in a balanced–differential, or single–ended configuration. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. A precision data shaper has a hold function to preset the shaper for fast recovery of new data.

Applications for the MC13156 include CT–2, wideband data links and other radio systems utilizing GMSK, FSK or FM modulation.

- 2.0 to 6.0 Vdc Operation
- Typical Sensitivity at 200 MHz of 2.0 μV for 12 dB SINAD
- RSSI Dynamic Range Typically 80 dB
- High Performance Data Shaper for Enhanced CT–2 Operation
- Internal 330 Ω and 1.4 kΩ Terminations for 10.7 MHz and 455 kHz Filters
- Split IF for Improved Filtering and Extended RSSI Range
- 3rd Order Intercept (Input) of –25 dBm (Input Matched)

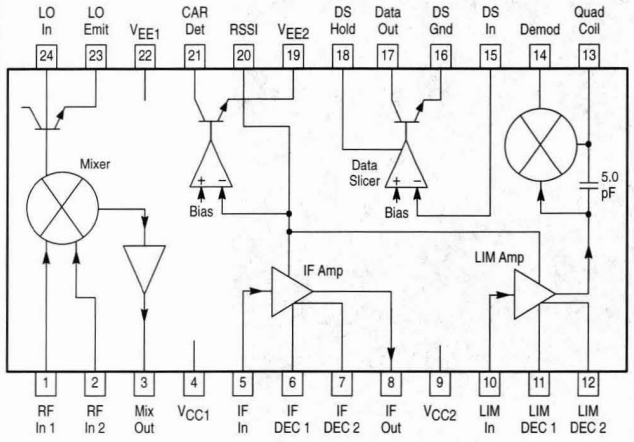



**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
(SO–24L)

**FB SUFFIX**
PLASTIC QFP PACKAGE
CASE 873

8

**Simplified Block Diagram**




**NOTE**: Pin Numbers shown for SOIC package only. Refer to Pin Assignments Table.

This device contains 197 active transistors.

**PIN CONNECTIONS**

| Function | SO–24L | QFP |
|---|---|---|
| RF Input 1 | 1 | 31 |
| RF Input 2 | 2 | 32 |
| Mixer Output | 3 | 1 |
| $V_{CC1}$ | 4 | 2 |
| IF Amp Input | 5 | 3 |
| IF Amp Decoupling 1 | 6 | 4 |
| IF Amp Decoupling 2 | 7 | 5 |
| $V_{CC}$ Connect (N/C Internal) | – | 6 |
| IF Amp Output | 8 | 7 |
| $V_{CC2}$ | 9 | 8 |
| Limiter IF Input | 10 | 9 |
| Limiter Decoupling 1 | 11 | 10 |
| Limiter Decoupling 2 | 12 | 11 |
| $V_{CC}$ Connect (N/C Internal) | – | 12, 13, 14 |
| Quad Coil | 13 | 15 |
| Demodulator Output | 14 | 16 |
| Data Slicer Input | 15 | 17 |
| $V_{CC}$ Connect (N/C Internal) | – | 18 |
| Data Slicer Ground | 16 | 19 |
| Data Slicer Output | 17 | 20 |
| Data Slicer Hold | 18 | 21 |
| $V_{EE2}$ | 19 | 22 |
| RSSI Output/Carrier Detect In | 20 | 23 |
| Carrier Detect Output | 21 | 24 |
| $V_{EE1}$ and Substrate | 22 | 25 |
| LO Emitter | 23 | 26 |
| LO Base | 24 | 27 |
| $V_{CC}$ Connect (N/C Internal) | – | 28, 29, 30 |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13156DW | $T_A$ = –40 to +85°C | SO–24L |
| MC13156FB | | QFP |

## MAXIMUM RATINGS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 16, 19, 22 | $V_{EE(max)}$ | –6.5 | Vdc |
| Junction Temperature | – | $T_{J(max)}$ | 150 | °C |
| Storage Temperature Range | – | $T_{stg}$ | –65 to +150 | °C |

**NOTES:** 1. Devices should not be operated at or outside these values. The "Recommended Operating Conditions" table provides for actual device operation.
2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage @ $T_A$ = 25°C<br>–40°C ≤ $T_A$ ≤ +85°C | 4, 9<br>16, 19, 22 | $V_{CC}$<br>$V_{EE}$ | 0 (Ground)<br>–2.0 to –6.0 | Vdc |
| Input Frequency | 1, 2 | $f_{in}$ | 500 | MHz |
| Ambient Temperature Range | – | $T_A$ | –40 to +85 | °C |
| Input Signal Level | 1, 2 | $V_{in}$ | 200 | mVrms |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = 0, no input signal.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Total Drain Current (See Figure 2) | 19, 22 | $I_{Total}$ | | | | mA |
| $V_{EE}$ = –2.0 Vdc | | | – | 4.8 | – | |
| $V_{EE}$ = –3.0 Vdc | | | 3.0 | 5.0 | 8.0 | |
| $V_{EE}$ = –5.0 Vdc | | | – | 5.2 | – | |
| $V_{EE}$ = –6.0 Vdc | | | – | 5.4 | – | |
| Drain Current, $I_{22}$ (See Figure 3) | 22 | $I_{22}$ | | | | mA |
| $V_{EE}$ = –2.0 Vdc | | | – | 3.0 | – | |
| $V_{EE}$ = –3.0 Vdc | | | – | 3.1 | – | |
| $V_{EE}$ = –5.0 Vdc | | | – | 3.3 | – | |
| $V_{EE}$ = –6.0 Vdc | | | – | 3.4 | – | |
| Drain Current, $I_{19}$ (See Figure 3) | 19 | $I_{19}$ | | | | mA |
| $V_{EE}$ = –2.0 Vdc | | | – | 1.8 | – | |
| $V_{EE}$ = –3.0 Vdc | | | – | 1.9 | – | |
| $V_{EE}$ = –5.0 Vdc | | | – | 1.9 | – | |
| $V_{EE}$ = –6.0 Vdc | | | – | 2.0 | – | |

**DATA SLICER** (Input Voltage Referenced to $V_{EE}$ = –3.0 Vdc, no input signal; See Figure 15.)

| | | | | | | |
|---|---|---|---|---|---|---|
| Input Threshold Voltage (High $V_{in}$) | 15 | $V_{15}$ | 1.0 | 1.1 | 1.2 | Vdc |
| Output Current (Low $V_{in}$)<br>Data Slicer Enabled (No Hold)<br>$V_{15}$ > 1.1 Vdc<br>$V_{18}$ = 0 Vdc | 17 | $I_{17}$ | – | 1.7 | – | mA |

## AC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{EE}$ = –3.0 Vdc, $f_{RF}$ = 130 MHz, $f_{LO}$ = 140.7 MHz, Figure 1 test circuit, unless otherwise specified.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| 12 dB SINAD Sensitivity (See Figures 17, 25)<br>$f_{in}$ = 144.45 MHz; $f_{mod}$ = 1.0 kHz; $f_{dev}$ = ±75 kHz | 1, 14 | – | – | –100 | – | dBm |
| **MIXER** | | | | | | |
| Conversion Gain<br>$P_{in}$ = –37 dBm (Figure 4) | 1, 3 | – | – | 22 | – | dB |
| Mixer Input Impedance | 1, 2 | $R_p$ | – | 1.0 | – | kΩ |
| Single–Ended (Table 1) | | $C_p$ | – | 4.0 | – | pF |
| Mixer Output Impedance | 3 | – | – | 330 | – | Ω |
| **IF AMPLIFIER SECTION** | | | | | | |
| IF RSSI Slope (Figure 6) | 20 | – | 0.2 | 0.4 | 0.6 | μA/dB |
| IF Gain (Figure 5) | 5, 8 | – | – | 39 | – | dB |
| Input Impedance | 5 | – | – | 1.4 | – | kΩ |
| Output Impedance | 8 | – | – | 290 | – | Ω |

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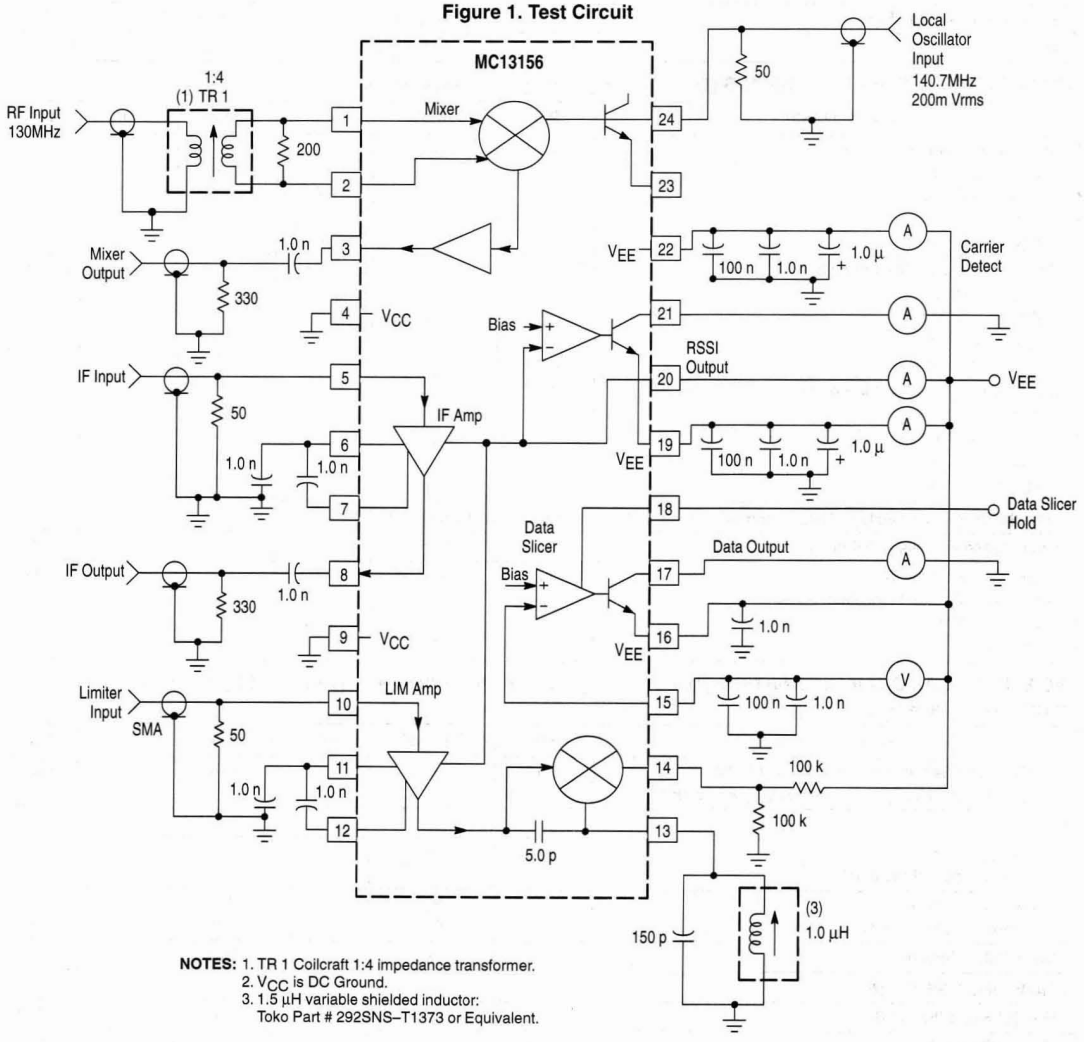
**AC ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{EE}$ = –3.0 Vdc, $f_{RF}$ = 130 MHz, $f_{LO}$ = 140.7 MHz, Figure 1 test circuit, unless otherwise specified.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **LIMITING AMPLIFIER SECTION** | | | | | | |
| Limiter RSSI Slope (Figure 7) | 20 | – | 0.2 | 0.4 | 0.6 | μA/dB |
| Limiter Gain | – | – | – | 55 | – | dB |
| Input Impedance | 10 | – | – | 1.4 | – | kΩ |
| **CARRIER DETECT** | | | | | | |
| Output Current – Carrier Detect (High $V_{in}$) | 21 | – | – | 0 | – | μA |
| Output Current – Carrier Detect (Low $V_{in}$) | 21 | – | – | 3.0 | – | mA |
| Input Threshold Voltage – Carrier Detect<br>Input Voltage Referenced to $V_{EE}$ = –3.0 Vdc | 20 | – | 0.9 | 1.2 | 1.4 | Vdc |

**Figure 1. Test Circuit**




**NOTES:** 1. TR 1 Coilcraft 1:4 impedance transformer.
2. $V_{CC}$ is DC Ground.
3. 1.5 μH variable shielded inductor:
Toko Part # 292SNS–T1373 or Equivalent.

**Figure 2. Total Drain Current versus Supply Voltage and Temperature**

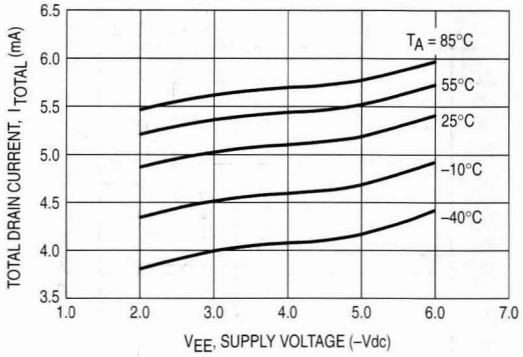



**Figure 3. Drain Currents versus Supply Voltage**

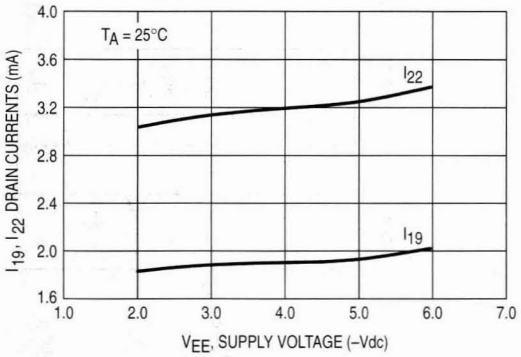



**Figure 4. Mixer Gain versus Input Signal Level**

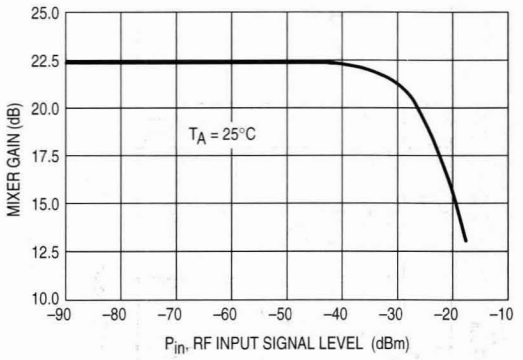



**Figure 5. IF Amplifier Gain versus Input Signal Level and Ambient Temperature**

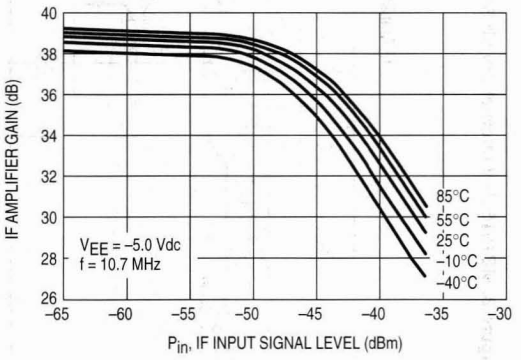



**Figure 6. IF Amplifier RSSI Output Current versus Input Signal Level and Ambient Temperature**

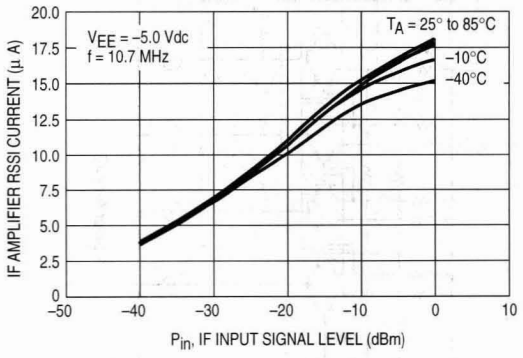



**Figure 7. Limiter Amplifier RSSI Output Current versus Input Signal Level and Temperature**

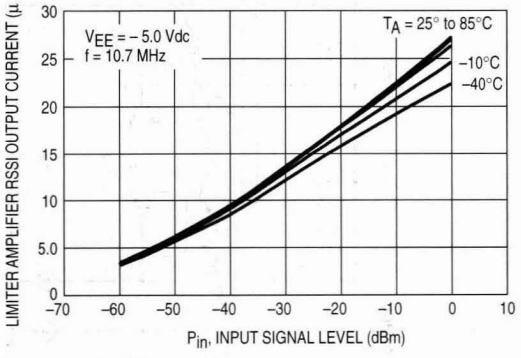



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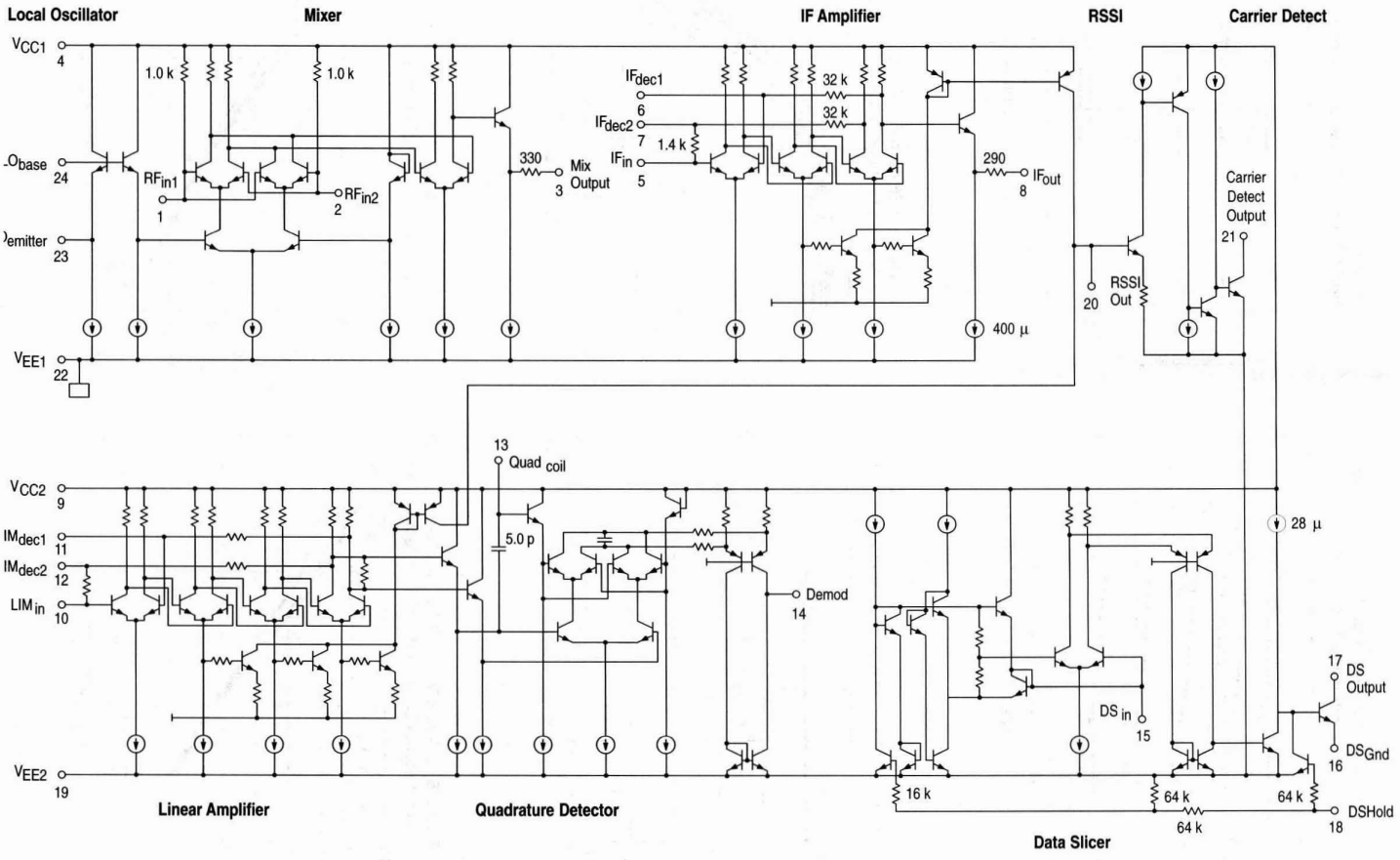
**Figure 8. MC13156DW Internal Circuit Schematic**



## CIRCUIT DESCRIPTION

### General

The MC13156 is a low power single conversion wideband FM receiver incorporating a split IF. This device is designated for use as the backend in digital FM systems such as CT–2 and wideband data links with data rates up to 500 kbaud. It contains a mixer, oscillator, signal strength meter drive, IF amplifier, limiting IF, quadrature detector and a data slicer with a hold function (refer to Figure 8, Simplified Internal Circuit Schematic).

### Current Regulation

Temperature compensating voltage independent current regulators are used throughout.

### Mixer

The mixer is a double–balanced four quadrant multiplier and is designed to work up to 500 MHz. It can be used in differential or in single–ended mode by connecting the other input to the positive supply rail.

Figure 4 shows the mixer gain and saturated output response as a function of input signal drive. The circuit used to measure this is shown in Figure 1. The linear gain of the mixer is approximately 22 dB. Figure 9 shows the mixer gain versus the IF output frequency with the local oscillator of 150 MHz at 100 mVrms LO drive level. The RF frequency is swept. The sensitivity of the IF output of the mixer is shown in Figure 10 for an RF input drive of 10 mVrms at 140 MHz and IF at 10 MHz.

The single–ended parallel equivalent input impedance of the mixer is Rp ~ 1.0 kΩ and Cp ~ 4.0 pF (see Table 1 for details). The buffered output of the mixer is internally loaded resulting in an output impedance of 330 Ω.

### Local Oscillator

The on–chip transistor operates with crystal and LC resonant elements up to 220 MHz. Series resonant, overtone crystals are used to achieve excellent local oscillator stability. 3rd overtone crystals are used through about 65 to 70 MHz. Operation from 70 MHz up to 180 MHz is feasible using the on–chip transistor with a 5th or 7th overtone crystal. To enhance operation using an overtone crystal, the internal transistor's bias is increased by adding an external resistor from Pin 23 to $V_{EE}$. –10 dBm of local oscillator drive is needed to adequately drive the mixer (Figure 10).

The oscillator configurations specified above, and two others using an external transistor, are described in the application section:

1) A 133 MHz oscillator multiplier using a 3rd overtone crystal, and
2) A 307.8 to 309.3 MHz manually tuned, varactor controlled local oscillator.

### RSSI

The Received Signal Strength Indicator (RSSI) output is a current proportional to the log of the received signal amplitude. The RSSI current output is derived by summing the currents from the IF and limiting amplifier stages. An external resistor at Pin 20 sets the voltage range or swing of the RSSI output voltage. Linearity of the RSSI is optimized by using external ceramic or crystal bandpass filters which have an insertion loss of 8.0 dB. The RSSI circuit is designed to provide 70+ dB of dynamic range with temperature compensation (see Figures 6 and 7 which show RSSI responses of the IF and Limiter amplifiers). Variation in the RSSI output current with supply voltage is small (see Figure 11).

### Carrier Detect

When the meter current flowing through the meter load resistance reaches 1.2 Vdc above ground, the comparator flips, causing the carrier detect output to go high. Hysteresis can be accomplished by adding a very large resistor for positive feedback between the output and the input of the comparator.

### IF Amplifier

The first IF amplifier section is composed of three differential stages with the second and third stages contributing to the RSSI. This section has internal dc feedback and external input decoupling for improved symmetry and stability. The total gain of the IF amplifier block is approximately 39 dB at 10.7 MHz. Figure 5 shows the gain and saturated output response of the IF amplifier over temperature, while Figure 12 shows the IF amplifier gain as a function of the IF frequency.

The fixed internal input impedance is 1.4 kΩ. It is designed for applications where a 455 kHz ceramic filter is used and no external output matching is necessary since the filter requires a 1.4 kΩ source and load impedance.

For 10.7 MHz ceramic filter applications, an external 430 Ω resistor must be added in parallel to provide the equivalent load impedance of 330 Ω that is required by the filter; however, no external matching is necessary at the input since the mixer output matches the 330 Ω source impedance of the filter. For 455 kHz applications, an external 1.1 kΩ resistor must be added in series with the mixer output to obtain the required matching impedance of 1.4 kΩ of the filter input resistance. Overall RSSI linearity is dependent on having total midband attenuation of 12 dB (6.0 dB insertion loss plus 6.0 dB impedance matching loss) for the filter. The output of the IF amplifier is buffered and the impedance is 290 Ω.

### Limiter

The limiter section is similar to the IF amplifier section except that four stages are used with the last three contributing to the RSSI. The fixed internal input impedance is 1.4 kΩ. The total gain of the limiting amplifier section is approximately 55 dB. This IF limiting amplifier section internally drives the quadrature detector section.

**Figure 9. Mixer Gain versus IF Frequency**

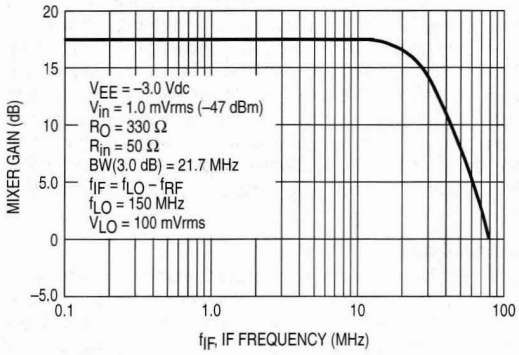



**Figure 10. Mixer IF Output Level versus Local Oscillator Input Level**

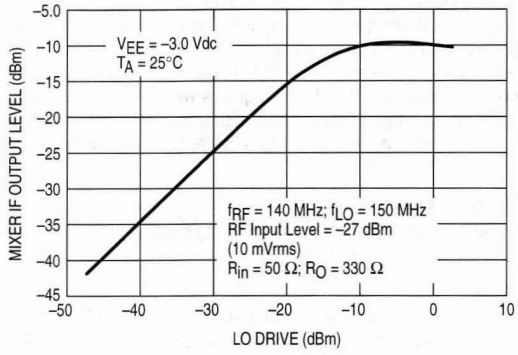



**Figure 11. RSSI Output Current versus Supply Voltage and RF Input Signal Level**

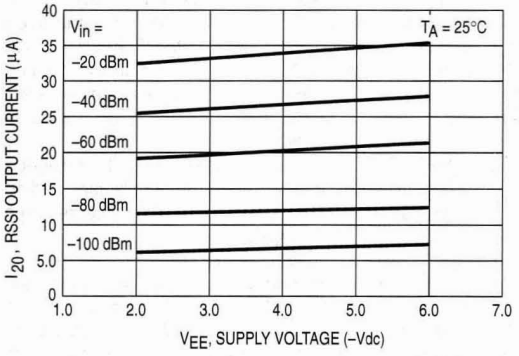



**Figure 12. IF Amplifier Gain versus IF Frequency**

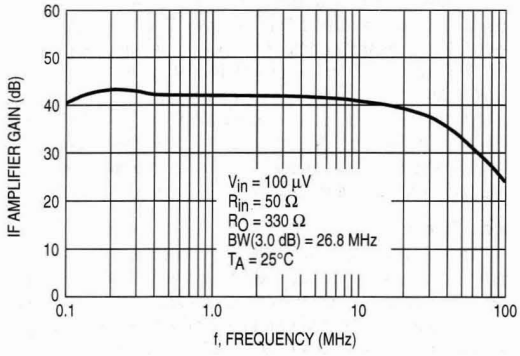
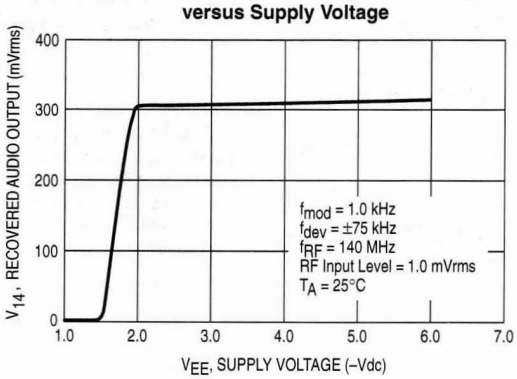



**Figure 13. Recovered Audio Output Voltage versus Supply Voltage**

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### Quadrature Detector

The quadrature detector is a doubly balanced four quadrant multiplier with an internal 5.0 pF quadrature capacitor to couple the IF signal to the external parallel RLC resonant circuit that provides the 90 degree phase shift and drives the quadrature detector. A single pin (Pin 13) provides for the external LC parallel resonant network and the internal connection to the quadrature detector.

The bandwidth of the detector allows for recovery of relatively high data rate modulation. The recovered signal is converted from differential to single ended through a push–pull NPN/PNP output stage. Variation in recovered audio output voltage with supply voltage is very small (see Figure 13). The output drive capability is approximately ±9.0 μA for a frequency deviation of ±75 kHz and 1.0 kHz modulating frequency (see Application Circuit).

### Data Slicer

The data slicer input (Pin 15) is self centering around 1.1 V with clamping occurring at 1.1 ± 0.5 $V_{be}$ Vdc. It is designed to square up the data signal. Figure 14 shows a detailed schematic of the data slicer.

The Voltage Regulator sets up 1.1 Vdc on the base of Q12, the Differential Input Amplifier. There is a potential of 1.0 $V_{be}$ on the base–collector of transistor diode Q11 and 2.0 $V_{be}$ on the base–collector of Q10. This sets up a 1.5 $V_{be}$ (~ 1.1 Vdc) on the node between the 36 kΩ resistors which is connected to the base of Q12. The differential output of the data slicer Q12 and Q13 is converted to a single–ended output by the Driver Circuit. Additional circuitry, not shown in Figure 14, tends to keep the data slicer input centered at 1.1 Vdc as input signal levels vary.

The Input Diode Clamp Circuit provides the clamping at 1.0 $V_{be}$ (0.75 Vdc) and 2.0 $V_{be}$ (1.45 Vdc). Transistor diodes Q7 and Q8 are on, thus, providing a 2.0 $V_{be}$ potential at the base of Q1. Also, the voltage regulator circuit provides a potential of 2.0 Vbe on the base of Q3 and 1.0 $V_{be}$ on the emitter of Q3 and Q2. When the data slicer input (Pin 15) is pulled up, Q1 turns off; Q2 turns on, thereby clamping the input at 2.0 $V_{be}$. On the other hand, when Pin 15 is pulled down, Q1 turns on; Q2 turns off, thereby clamping the input at 1.0 $V_{be}$.

The recovered data signal from the quadrature detector is ac coupled to the data slicer via an input coupling capacitor. The size of this capacitor and the nature of the data signal determine how faithfully the data slicer shapes up the recovered signal. The time constant is short for large peak to peak voltage swings or when there is a change in dc level at the detector output. For small signal or for continuous bits of the same polarity which drift close to the threshold voltage, the time constant is longer. When centered there is no input current allowed, which is to say, that the input looks high in impedance.

Another unique feature of the data slicer is that it responds to various logic levels applied to the Data Slicer Hold Control pin (Pin 18). Figure 15 illustrates how the input and output currents under "no hold" condition relate to the input voltage. Figure 16 shows how the input current and input voltage relate for both the "no hold" and "hold" condition.

The hold control (Pin18) does three separate tasks:

1) With Pin 18 at 1.0 $V_{be}$ or greater, the output is shut off (sets high). Q19 turns on which shunts the base drive from Q20, thereby turning the output off.
2) With Pin 18 at 2.0 $V_{be}$ or greater, internal clamping diodes are open circuited and the comparator input is shut off and effectively open circuited. This is accomplished by turning off the current source to emitters of the input differential amplifier, thus, the input differential amplifier is shut off.
3) When the input is shut off, it allows the input capacitor to hold its charge during transmit to improve recovery at the beginning of the next receive period. When it is turned on, it allows for very fast charging of the input capacitor for quick recovery of new tuning or data average. The above features are very desirable in a TDD digital FM system.

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**Figure 14. Data Slicer Circuit**

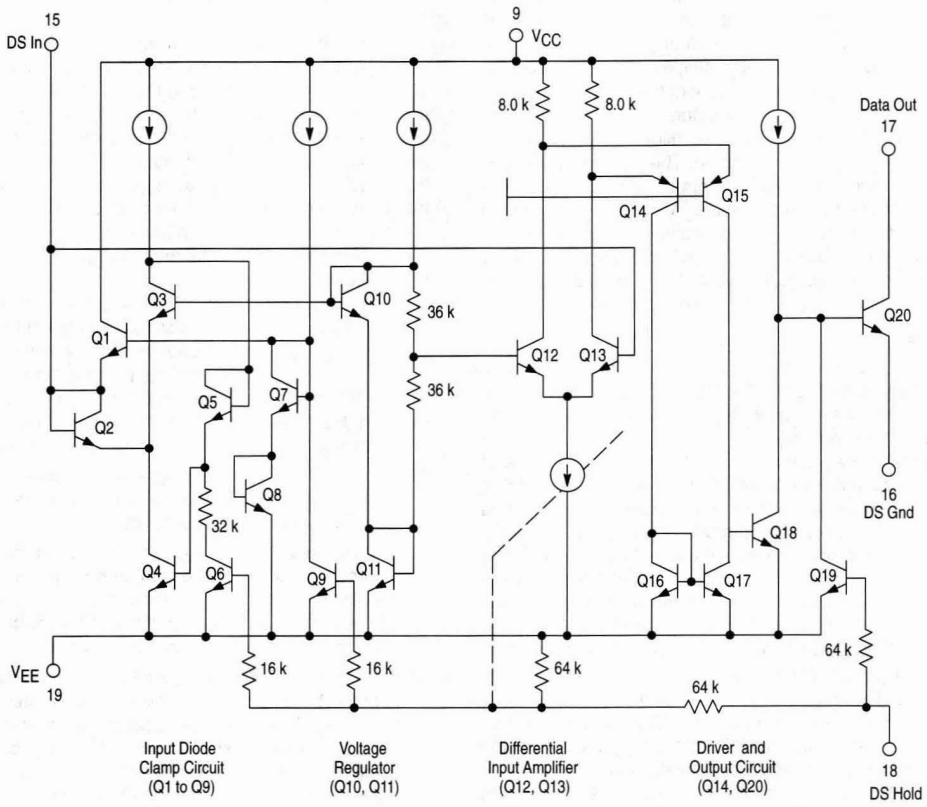


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**Figure 15. Data Slicer Input/Output Currents versus Input Voltage**

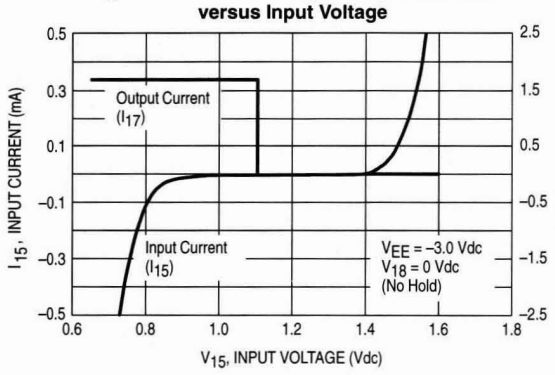



**Figure 16. Data Slicer Input Current versus Input Voltage**

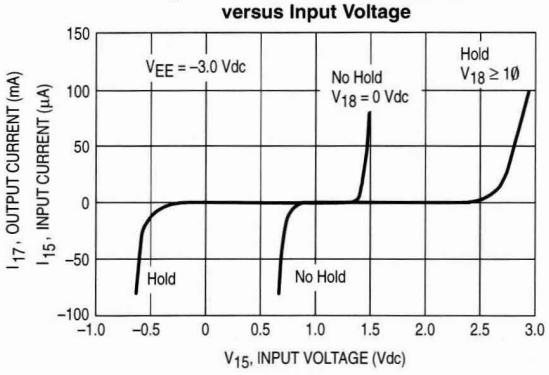
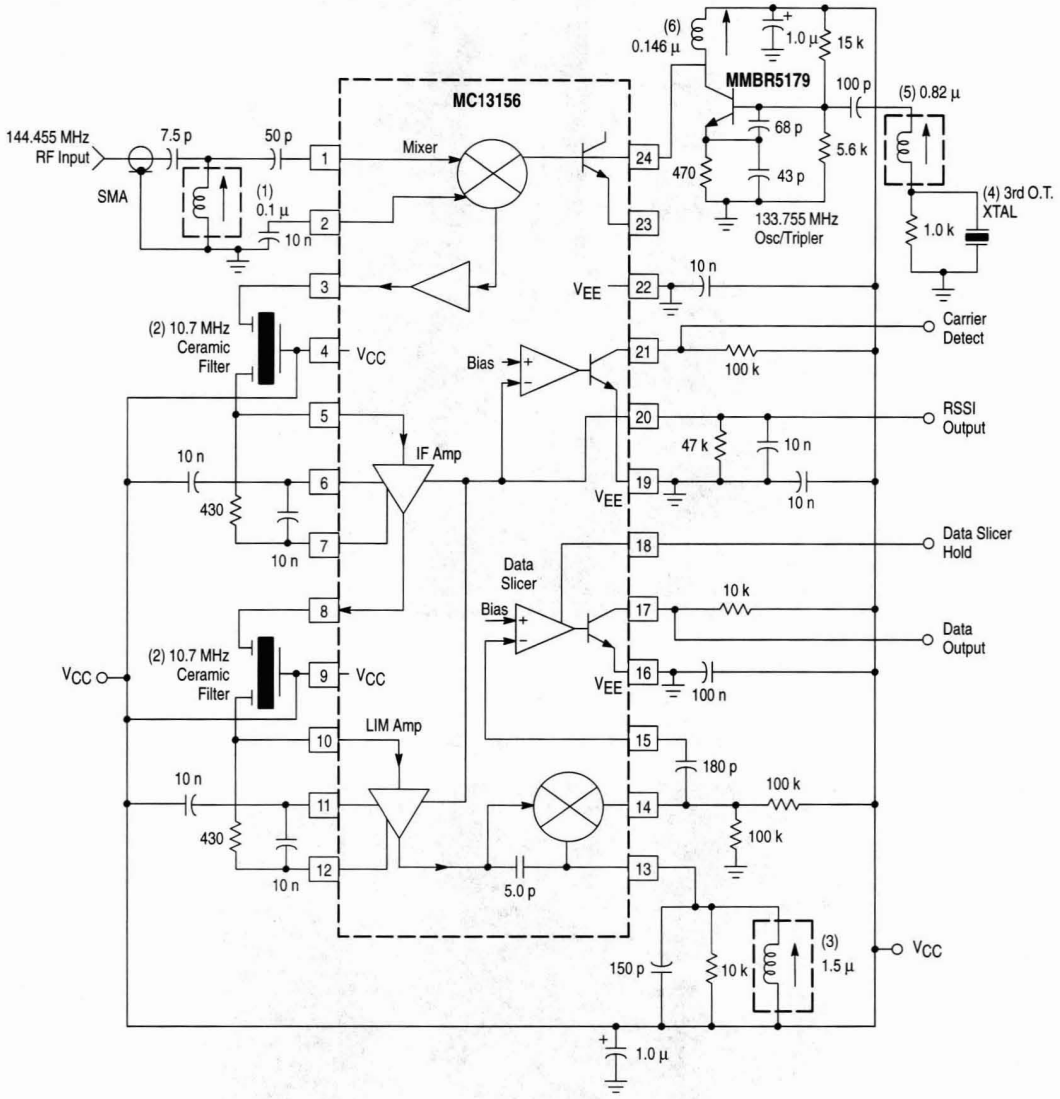


**Figure 17. MC13156DW Application Circuit**




**NOTES:** 1. 0.1 µH Variable Shielded Inductor: Coilcraft part # M1283–A or equivalent.
2. 10.7 MHz Ceramic Filter: Toko part # SK107M5–A0–10X or Murata Erie part # SFE10.7MHY–A.
3. 1.5 µH Variable Shielded Inductor: Toko part # 292SNS–T1373.
4. 3rd Overtone, Series Resonant, 25 PPM Crystal at 44.585 MHz.
5. 0.814 µH Variable Shielded Inductor: Coilcraft part # 143–18J12S.
6. 0.146 µH Variable Inductor: Coilcraft part # 146–04J08.

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Figure 18. MC13156DW Circuit Side Component Placement

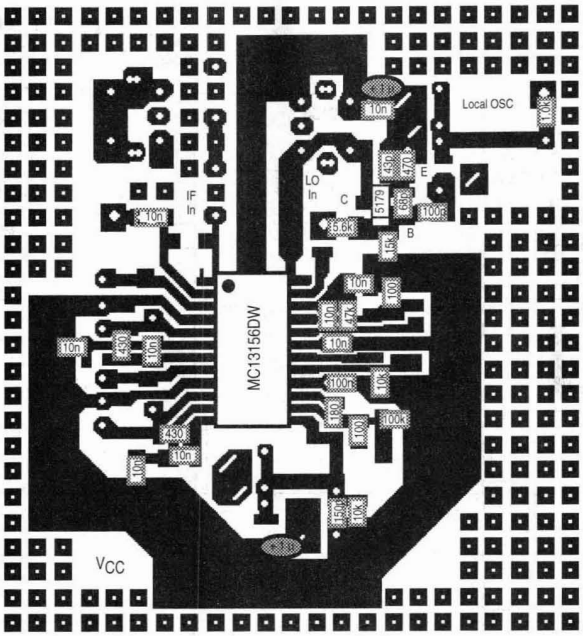


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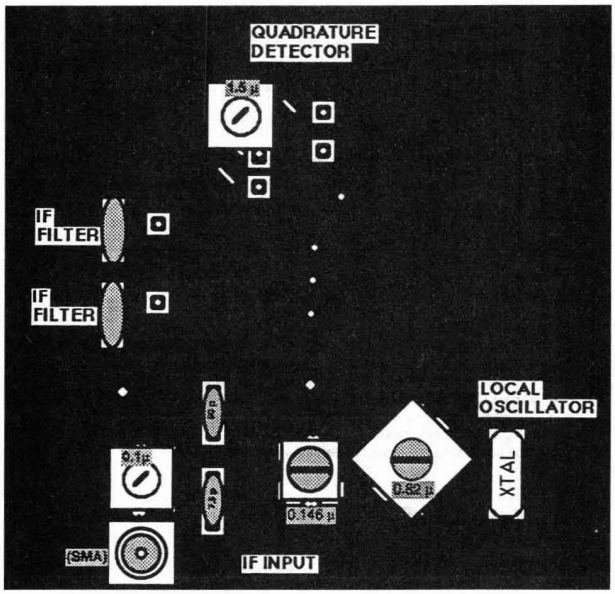
Figure 19. MC13156DW Ground Side Component Placement



## APPLICATIONS INFORMATION

### Component Selection

The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers and coil types. Figures 18 and 19 show the placement for the components specified in the application circuit (Figure 17). The applications circuit schematic specifies particular components that were used to achieve the results shown in the typical curves and tables but equivalent components should give similar results.

### Input Matching Networks/Components

The input matching circuit shown in the application circuit schematic is passive high pass network which offers effective image rejection when the local oscillator is below the RF input frequency. Silver mica capacitors are used for their high Q and tight tolerance. The PC board is not dedicated to any particular input matching network topology; space is provided for the designer to breadboard as desired.

Alternate matching networks using 4:1 surface mount transformers or BALUNs provide satisfactory performance. The 12 dB SINAD sensitivity using the above matching networks is typically –100 dBm for $f_{mod}$ = 1.0 kHz and $f_{dev}$ = ±75 kHz at $f_{IN}$ = 144.45 MHz and $f_{OSC}$ = 133.75 MHz (see Figure 25).

It is desirable to use a SAW filter before the mixer to provide additional selectivity and adjacent channel rejection and improved sensitivity. The SAW filter should be designed to interface with the mixer input impedance of approximately 1.0 kΩ. Table 1 displays the series equivalent single–ended mixer input impedance.

### Local Oscillators

**VHF Applications** – The local oscillator circuit shown in the application schematic utilizes a third overtone crystal and an RF transistor. Selecting a transistor having good phase noise performance is important; a mandatory criteria is for the device to have good linearity of beta over several decades of collector current. In other words, if the low current beta is suppressed, it will not offer good 1/f noise performance. A third overtone series resonant crystal having at least 25 ppm tolerance over the operating temperature is recommended. The local oscillator is an impedance inversion third overtone Colpitts network and harmonic generator. In this circuit a 560 to 1.0 kΩ resistor shunts the crystal to ensure that it operates in its overtone mode; thus, a blocking capacitor is needed to eliminate the dc path to ground. The resulting parallel LC network should "free–run" near the crystal frequency if a short to ground is placed across the crystal. To provide sufficient output loading at the collector, a high Q variable inductor is used that is tuned to self resonate at the 3rd harmonic of the overtone crystal frequency.

The on–chip grounded collector transistor may be used for HF and VHF local oscillator with higher order overtone crystals. Figure 20 shows a 5th overtone oscillator at 93.3 MHz and Figure 21 shows a 7th overtone oscillator at 148.3 MHz. Both circuits use a Butler overtone oscillator configuration. The amplifier is an emitter follower. The crystal is driven from the emitter and is coupled to the high impedance base through a capacitive tap network. Operation at the desired overtone frequency is ensured by the parallel resonant circuit formed by the variable inductor and the tap capacitors and parasitic capacitances of the on–chip transistor and PC board. The variable inductor specified in the schematic could be replaced with a high tolerance, high Q ceramic or air wound surface mount component if the other components have good tolerances. A variable inductor provides an adjustment for gain and frequency of the resonant tank ensuring lock up and startup of the crystal oscillator. The overtone crystal is chosen with ESR of typically 80 Ω and 120 Ω maximum; if the resistive loss in the crystal is too high, the performance of the oscillator may be impacted by lower gain margins.

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**Table 1. Mixer Input Impedance Data**
(Single–ended configuration, $V_{CC}$ = 3.0 Vdc, local oscillator drive = 100 mVrms)

| Frequency (MHz) | Series Equivalent Complex Impedance (R + jX) (Ω) | Parallel Resistance Rp (Ω) | Parallel Capacitance Cp (pF) |
|---|---|---|---|
| 90 | 190 – j380 | 950 | 4.7 |
| 100 | 160 – j360 | 970 | 4.4 |
| 110 | 130 – j340 | 1020 | 4.2 |
| 120 | 110 – j320 | 1040 | 4.2 |
| 130 | 97 – j300 | 1030 | 4.0 |
| 140 | 82 – j280 | 1040 | 4.0 |
| 150 | 71 – j270 | 1100 | 4.0 |
| 160 | 59 – j260 | 1200 | 3.9 |
| 170 | 52 – j240 | 1160 | 3.9 |
| 180 | 44 – j230 | 1250 | 3.8 |
| 190 | 38 – j220 | 1300 | 3.8 |

A series LC network to ground (which is $V_{CC}$) is comprised of the inductance of the base lead of the on–chip transistor and PC board traces and tap capacitors. Parasitic oscillations often occur in the 200 to 800 MHz range. A small resistor is placed in series with the base (Pin 24) to cancel the negative resistance associated with this undesired mode of oscillation. Since the base input impedance is so large a small resistor in the range of 27 to 68 Ω has very little effect on the desired Butler mode of oscillation.

The crystal parallel capacitance, $C_O$, provides a feedback path that is low enough in reactance at frequencies of 5th overtone or higher to cause trouble. $C_O$ has little effect near resonance because of the low impedance of the crystal motional arm ($R_m$–$L_m$–$C_m$). As the tunable inductor which forms the resonant tank with the tap capacitors is tuned off the crystal resonant frequency, it may be difficult to tell if the oscillation is under crystal control. Frequency jumps may occur as the inductor is tuned. In order to eliminate this behavior an inductor ($L_O$) is placed in parallel with the crystal. $L_O$ is chosen to resonant with the crystal parallel capacitance ($C_O$) at the desired operation frequency. The inductor provides a feedback path at frequencies well below resonance; however, the parallel tank network of the tap capacitors and tunable inductor prevent oscillation at these frequencies.

### UHF Application

Figure 22 shows a 318.5 to 320 MHz receiver which drives the mixer with an external varactor controlled (307.8 to 309.3 MHz) LC oscillator using an MPS901 (RF low power transistor in a TO–92 plastic package; also MMBR901 is available in a SOT–23 surface mount package). With the 50 kΩ 10 turn potentiometer this oscillator is tunable over a range of approximately 1.5 MHz. The MMBV909L is a low voltage varactor suitable for UHF applications; it is a dual back–to–back varactor in a SOT–23 package. The input matching network uses a 1:4 impedance matching transformer (Recommended sources are Mini–Circuits and Coilcraft).

Using the same IF ceramic filters and quadrature detector circuit as specified in the applications circuit in Figure 17, the 12 dB SINAD performance is –95 dBm for a $f_{mod}$ = 1.0 kHz sinusoidal waveform and $f_{dev}$ ±40 kHz.

This circuit is breadboarded using the evaluation PC board shown in Figures 32 and 33. The RF ground is $V_{CC}$ and path lengths are minimized. High quality surface mount components were used except where specified. The absolute values of the components used will vary with layout placement and component parasitics.

### RSSI Response

Figure 26 shows the full RSSI response in the application circuit. The 10.7 MHz, 110 kHz wide bandpass ceramic filters (recommended sources are TOKO part # SK107M5–AO–10X or Murata Erie SFE10.7MHY–A) provide the correct bandpass insertion loss to linearize the curve between the limiter and IF portions of RSSI. Figure 25 shows that limiting occurs at an input of –100 dBm. As shown in Figure 26, the RSSI output linear from –100 dBm to –30 dBm.

The RSSI rise and fall times for various RF input signal levels and R20 values are measured at Pin 20 without 10 nF filter capacitor. A 10 kHz square wave pulses the RF input signal on and off. Figure 27 shows that the rise and fall times are short enough to recover greater than 10 kHz ASK data; with a wider IF bandpass filters data rates up to 50 kHz may be achieved. The circuit used is the application circuit in Figure 17 with no RSSI output filter capacitor.

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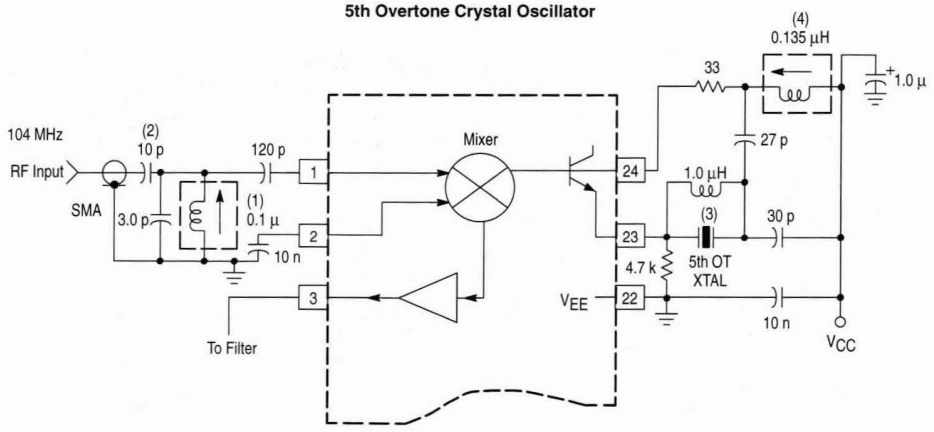
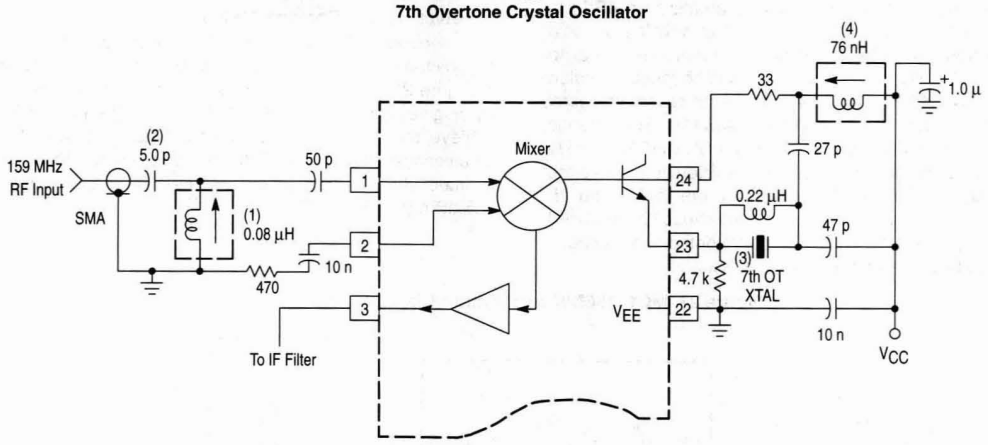
**Figure 20. MC13156DW Application Circuit**
**$f_{RF}$ = 104 MHz; $f_{LO}$ = 93.30 MHz**
**5th Overtone Crystal Oscillator**




**NOTES:** 1. 0.1 µH Variable Shielded Inductor: Coilcraft part # M1283–A or equivalent.
2. Capacitors are Silver Mica.
3. 5th Overtone, Series Resonant, 25 PPM Crystal at 93.300 MHz.
4. 0.135 µH Variable Shielded Inductor: Coilcraft part # 146–05J08S or equivalent.

**Figure 21. MC13156DW Application Circuit**
**$f_{RF}$ = 159 MHz; $f_{LO}$ = 148.30 MHz**
**7th Overtone Crystal Oscillator**




**NOTES:** 1. 0.08 µH Variable Shielded Inductor: Toko part # 292SNS–T1365Z or equivalent.
2. Capacitors are Silver Mica.
3. 7th Overtone, Series Resonant, 25 PPM Crystal at 148.300 MHz.
4. 76 nH Variable Shielded Inductor: Coilcraft part # 150–03J08S or equivalent.

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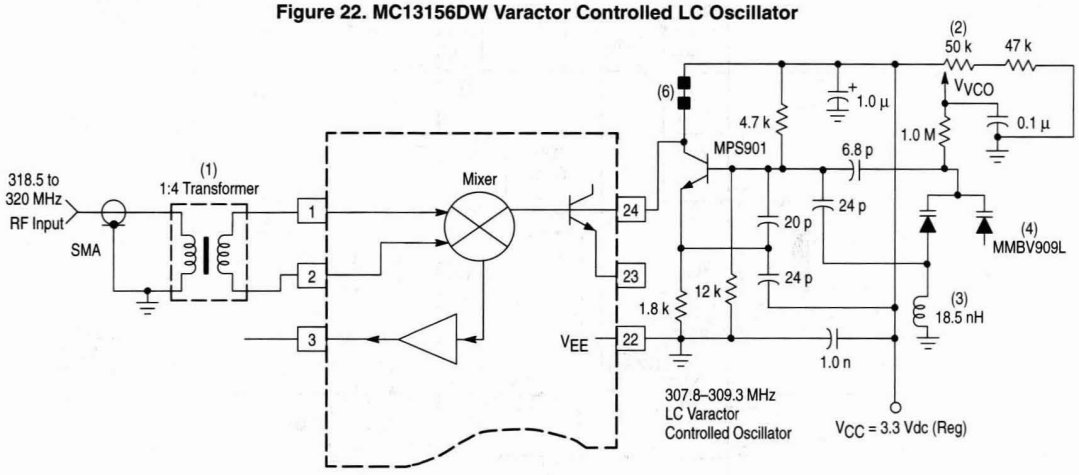
**Figure 22. MC13156DW Varactor Controlled LC Oscillator**




**NOTES:** 1. 1:4 Impedance Transformer: Mini–Circuits.
2. 50 k Potentiometer, 10 turns.
3. Spring Coil; Coilcraft A05T.
4. Dual Varactor in SOT–23 Package.
5. All other components are surface mount components.
6. Ferrite beads through loop of 24 AWG wire.

### 45 MHz Narrowband Receiver

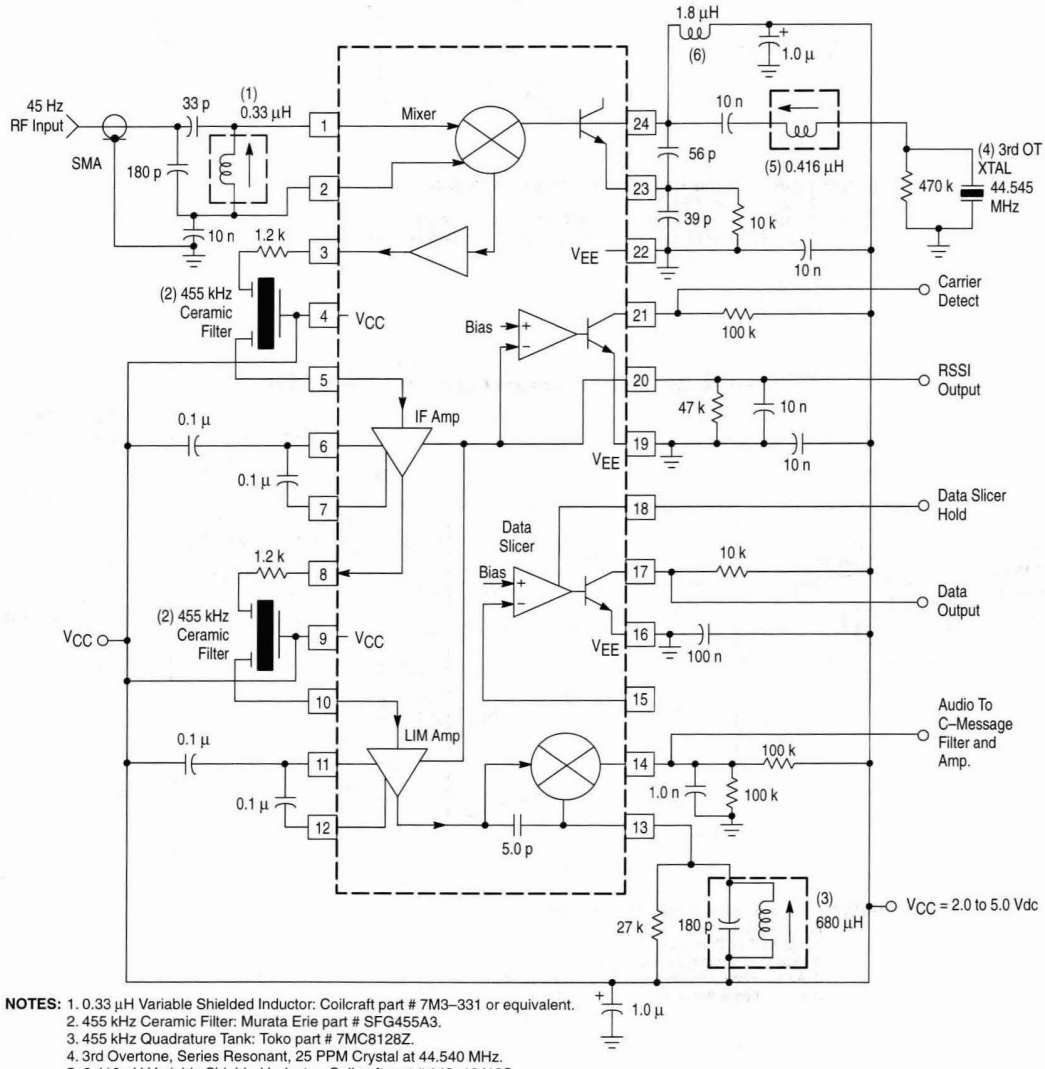
The above application examples utilize a 10.7 MHz IF. In this section a narrowband receiver with a 455 kHz IF will be described. Figure 23 shows a full schematic of a 45 MHz receiver that uses a 3rd overtone crystal with the on–chip oscillator transistor. The oscillator configuration is similar to the one used in Figure 17; it is called an impedance inversion Colpitts. A 44.545 MHz 3rd overtone, series resonant crystal is used to achieve an IF frequency at 455 kHz. The ceramic IF filters selected are Murata Erie part # SFG455A3. 1.2 kΩ chip resistors are used in series with the filters to achieve the terminating resistance of 1.4 kΩ to the filter. The IF decoupling is very important; 0.1 μF chip capacitors are used at Pins 6, 7, 11 and 12. The quadrature detector tank circuit uses a 455 kHz quadrature tank from Toko.

The 12 dB SINAD performance is –109 dBm for a $f_{mod}$ = 1.0 kHz and a $f_{dev}$ = ±4.0 kHz. The RSSI dynamic range is approximately 80 dB of linear range (see Figure 24).

### Receiver Design Considerations

The curves of signal levels at various portions of the application receiver with respect to RF input level are shown in Figure 28. This information helps determine the network topology and gain blocks required ahead of the MC13156 to achieve the desired sensitivity and dynamic range of the receiver system. In the application circuit the input third order intercept (IP3) performance of the system is approximately –25 dBm (see Figure 29).

**Figure 23. MC13156DW Application Circuit at 45 MHz**




**NOTES:** 1. 0.33 μH Variable Shielded Inductor: Coilcraft part # 7M3–331 or equivalent.
2. 455 kHz Ceramic Filter: Murata Erie part # SFG455A3.
3. 455 kHz Quadrature Tank: Toko part # 7MC8128Z.
4. 3rd Overtone, Series Resonant, 25 PPM Crystal at 44.540 MHz.
5. 0.416 μH Variable Shielded Inductor: Coilcraft part # 143–10J12S.
6. 1.8 μH Molded Inductor.

**Figure 24. RSSI Output Voltage versus Input Signal Level**

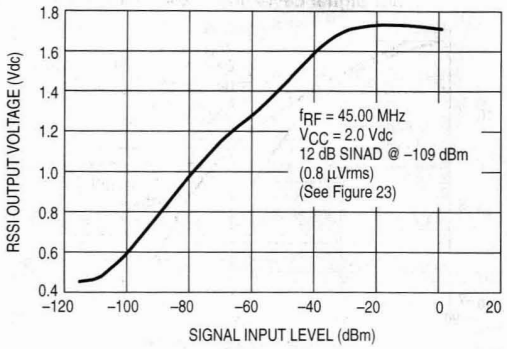



**Figure 25. S + N/N versus RF Input Signal Level**

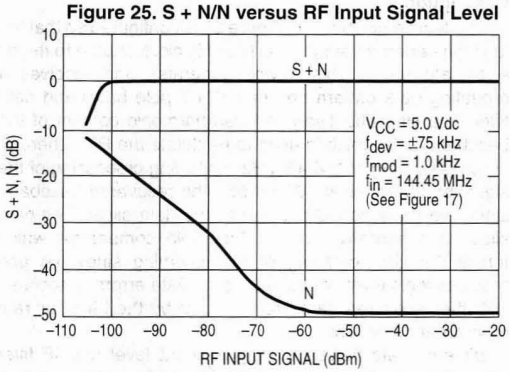



**Figure 26. RSSI Output Voltage versus Input Signal Level**

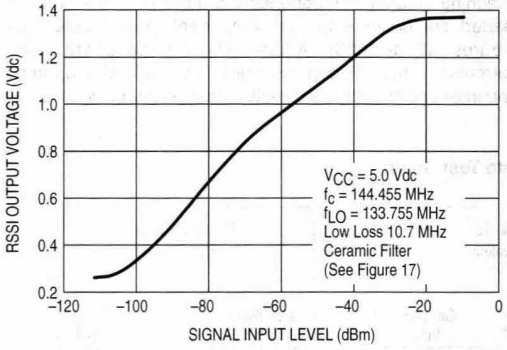



**Figure 27. RSSI Output Rise and Fall Times versus RF Input Signal Level**

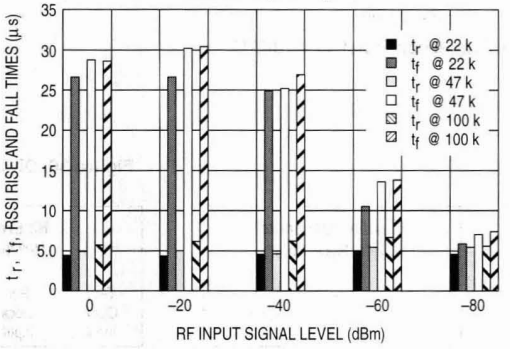



**Figure 28. Signal Levels versus RF Input Signal Level**

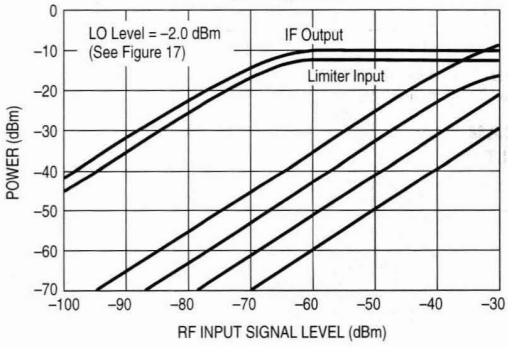
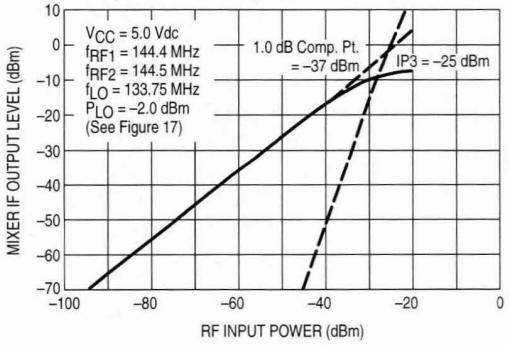



**Figure 29. 1.0 dB Compression Pt. and Input Third Order Intercept Pt. versus Input Power**

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## BER TESTING AND PERFORMANCE

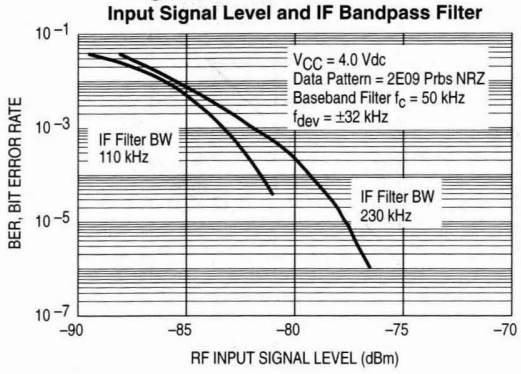
### Description

The test setup shown in Figure 30 is configured so that the function generator supplies a 100 kHz clock source to the bit error rate tester. This device generates and receives a repeating data pattern and drives a 5 pole baseband data filter. The filter effectively reduces harmonic content of the baseband data which is used to modulate the RF generator which is running at 144.45 MHz. Following processing of the signal by the receiver (MC13156), the recovered baseband sinewave (data) is AC coupled to the data slicer. The data slicer is essentially an auto–threshold comparator which tracks the zero crossing of the incoming sinewave and provides logic level data at its ouput. Data errors associated with the recovered data are collected by the bit error rate receiver and displayed.

Bit error rate versus RF signal input level and IF filter bandwidth are shown in Figure 31. The bit error rate data was taken under the following test conditions:

- Data rate = 100 kbps
- Filter cutoff frequency set to 39% of the data rate or 39 kHz.
- Filter type is a 5 pole equal–ripple with 0.5° phase error.
- $V_{CC}$ = 4.0 Vdc
- Frequency deviation = ±32 kHz.

**Figure 31. Bit Error Rate versus RF Input Signal Level and IF Bandpass Filter**




### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The center section of the board provides an area for attaching all SMT components to the circuit side and radial leaded components to the component ground side (see Figures 32 and 33). Additionally, the peripheral area surrounding the RF core provides pads to add supporting and interface circuitry as a particular application dictates.

8

**Figure 30. Bit Error Rate Test Setup**

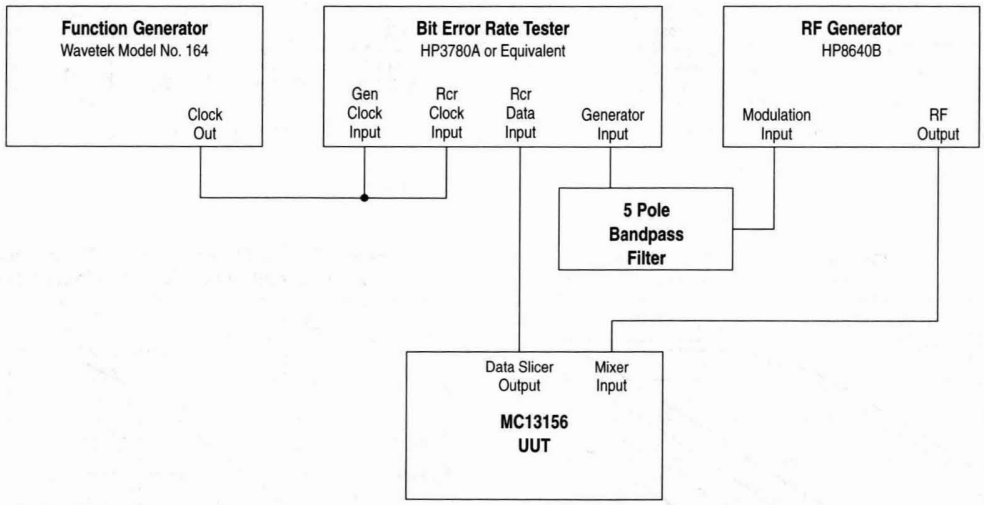


Figure 32. Circuit Side View

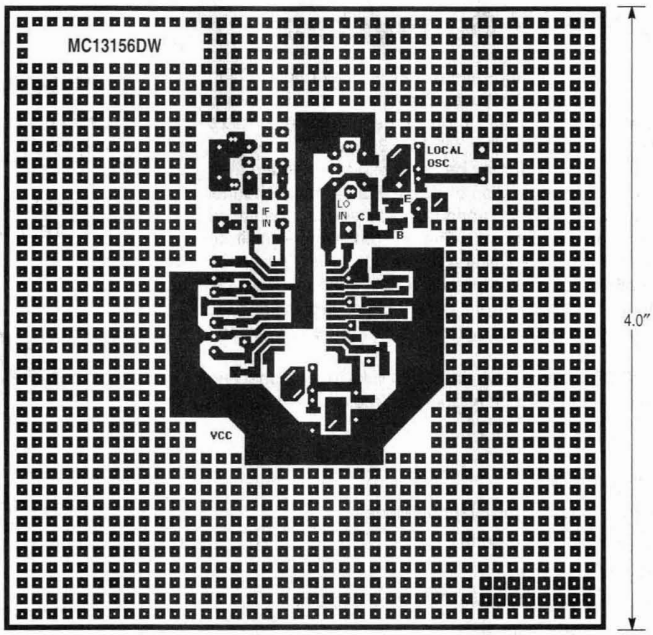
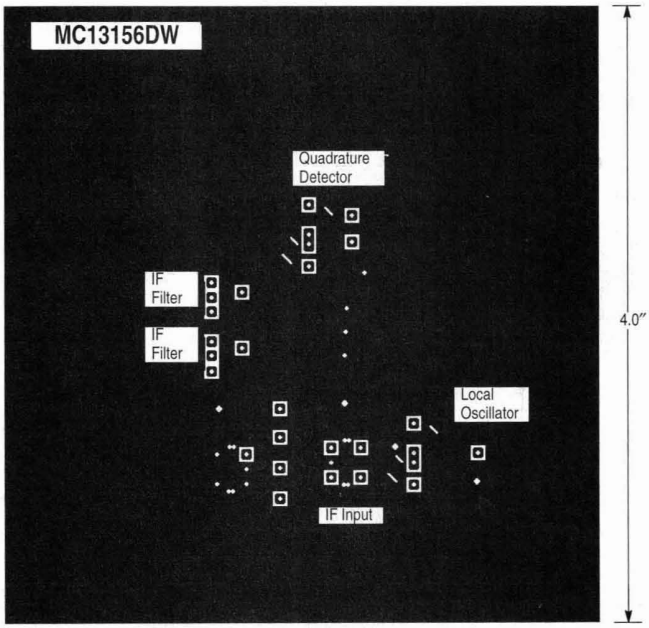





Figure 33. Ground Side View



MOTOROLA

# MC13158

## Wideband FM IF Subsystem

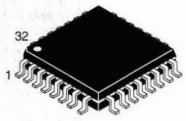
**WIDEBAND FM IF SUBSYSTEM FOR DECT AND DIGITAL APPLICATIONS**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13158 is a wideband IF subsystem that is designed for high performance data and analog applications. Excellent high frequency performance is achieved, with low cost, through the use of Motorola's MOSAIC 1.5™ RF bipolar process. The MC13158 has an on–board grounded collector VCO transistor that may be used with a fundamental or overtone crystal in single channel operation or with a PLL in multi–channel operation. The mixer is useful to 500 MHz and may be used in a balanced differential or single ended configuration. The IF amplifier is split to accommodate two low cost cascaded filters. RSSI output is derived by summing the output of both IF sections. A precision data shaper has an Off function to shut the output off to save current. An enable control is provided to power down the IC for power management in battery operated applications.

Applications include DECT, wideband wireless data links for personal and portable laptop computers and other battery operated radio systems which utilize GFSK, FSK or FM modulation.

- Designed for DECT Applications
- 1.8 to 6.0 Vdc Operating Voltage
- Low Power Consumption in Active and Standby Mode
- Greater than 600 kHz Detector Bandwidth
- Data Slicer with Special Off Function
- Enable Function for Power Down of Battery Operated Systems
- RSSI Dynamic Range of 80 dB Minimum
- Low External Component Count

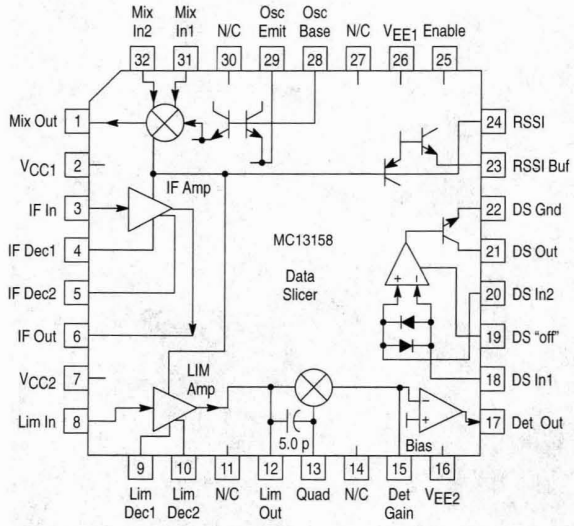



**FTB SUFFIX**
PLASTIC PACKAGE
CASE 873
(Thin QFP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13158FTB | $T_A$ = – 40 to +85°C | TQFP–32 |

**Representative Block Diagram**




This device contains 234 active transistors.

## MAXIMUM RATINGS

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage | 16, 26 | $V_{S(max)}$ | 6.5 | Vdc |
| Junction Temperature | | $T_{JMAX}$ | +150 | °C |
| Storage Temperature Range | | $T_{stg}$ | −65 to +150 | °C |

**NOTE:** 1. Devices should not be operated at or outside these values. The "Recommended Operating Conditions" provide for actual device operation.

## RECOMMENDED OPERATING CONDITIONS ($V_{CC} = V_2 = V_7$; $V_{EE} = V_{16} = V_{22} = V_{26}$; $V_S = V_{CC} - V_{EE}$)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage<br>$T_A$ = 25°C<br>−40°C ≤ $T_A$ ≤ 85°C | 2, 7<br><br>16, 26 | $V_S$ | 2.0 to 6.0 | Vdc |
| Input Frequency | 31, 32 | $F_{in}$ | 10 to 500 | MHz |
| Ambient Temperature Range | | $T_A$ | −40 to +85 | °C |
| Input Signal Level | 31, 32 | $V_{in}$ | 200 | mVrms |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C; $V_S$ = 3.0 Vdc; No Input Signal; See Figure 1.)

| Characteristic | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Total Drain Current | $V_S$ = 2.0 Vdc<br>$V_S$ = 3.0 Vdc<br>$V_S$ = 6.0 Vdc<br>See Figure 2 | 16, 26 | $I_{TOTAL}$ | 2.5<br>3.5<br>3.5 | 5.5<br>5.7<br>6.0 | 8.5<br>8.5<br>9.5 | mA |
| **DATA SLICER** (Input Voltage Referenced to $V_{EE}$; $V_S$ = 3.0 Vdc; No Input Signal) | | | | | | | |
| Output Current; $V_{18}$ LO;<br>Data Slicer Enabled (DS "on") | $V_{19} = V_{EE}$<br>$V_{18} < V_{20}$<br>$V_{20} = V_S/2$<br>See Figure 3 | 21 | $I_{21}$ | 2.0 | 5.9 | – | mA |
| Output Current; $V_{18}$ HI;<br>Data Slicer Enabled (DS "on") | $V_{19} = V_{EE}$<br>$V_{18} > V_{20}$<br>$V_{20} = V_S/2$<br>See Figure 4 | 21 | $I_{21}$ | – | 0.1 | 1.0 | μA |
| Output Current;<br>Data Slicer Disabled (DS "off") | $V_{19} = V_{CC}$<br>$V_{20} = V_S/2$ | 21 | $I_{21}$ | – | 0.1 | 1.0 | μA |

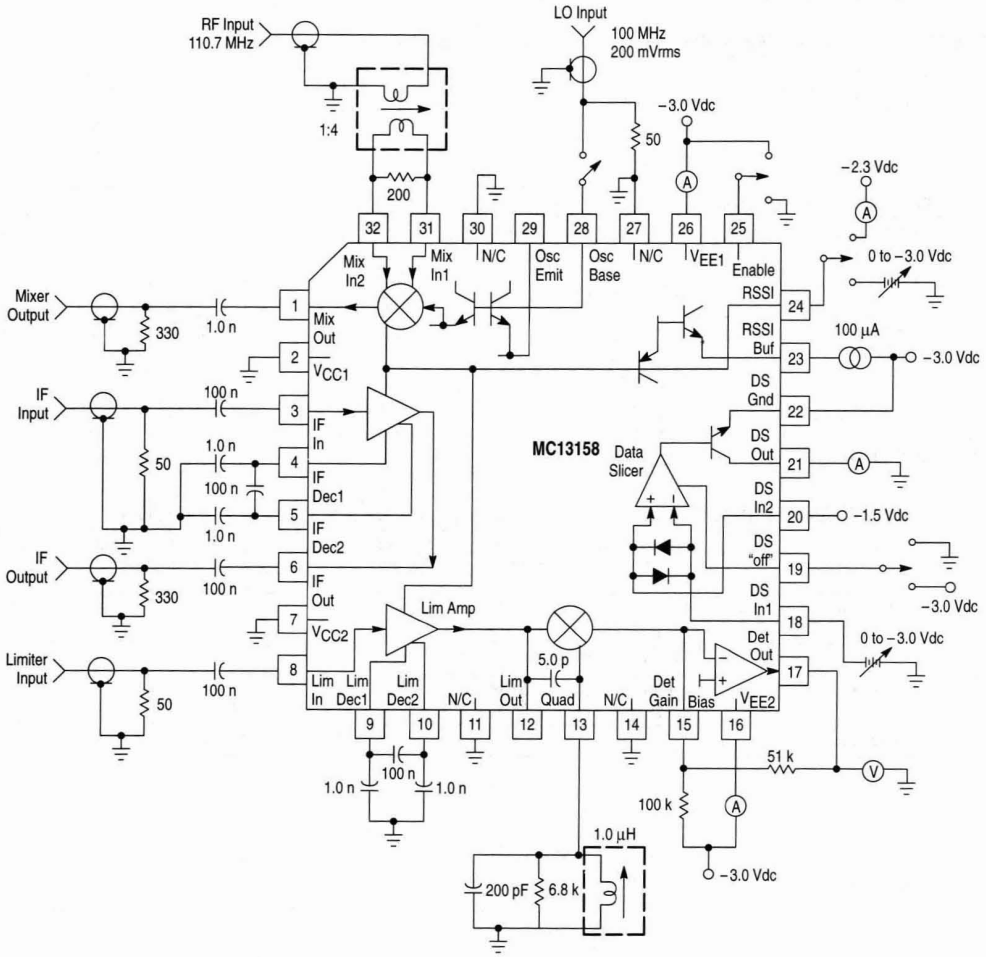
## AC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C; $V_S$ = 3.0 Vdc; $f_{RF}$ = 110.7 MHz; $f_{LO}$ = 100 MHz; See Figure 1.)

| Characteristic | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **MIXER** | | | | | | | |
| Mixer Conversion Gain | $V_{in}$ = 1.0 mVrms<br>See Figure 5 | 31, 32, 1 | – | – | 22 | – | dB |
| Noise Figure | Input Matched | 31, 32, 1 | NF | – | 14 | – | dB |
| Mixer Input Impedance | Single–Ended<br>See Figure 15 | 31, 32 | Rp<br>Cp | –<br>– | 865<br>1.6 | –<br>– | Ω<br>pF |
| Mixer Output Impedance | | 1 | – | – | 330 | – | Ω |

**AC ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C; $V_S$ = 3.0 Vdc; $f_{RF}$ = 110.7 MHz; $f_{LO}$ = 100 MHz; See Figure 1.)

| Characteristic | Condition | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **IF AMPLIFIER SECTION** | | | | | | | |
| IF RSSI Slope | See Figure 8 | 23 | – | 0.15 | 0.3 | 0.4 | μA/dB |
| IF Gain | f = 10.7 MHz<br>See Figure 7 | 3, 6 | – | – | 36 | – | dB |
| Input Impedance | | 3 | – | – | 330 | – | Ω |
| Output Impedance | | 6 | – | – | 330 | – | Ω |
| **LIMITING AMPLIFIER SECTION** | | | | | | | |
| Limiter RSSI Slope | See Figure 9 | 23 | – | 0.15 | 0.3 | 0.4 | μA/dB |
| Limiter Gain | f = 10.7 MHz | 8, 12 | – | – | 70 | – | dB |
| Input Impedance | | 8 | – | – | 330 | – | Ω |

**Figure 1. Test Circuit**



## Typical Performance Over Temperature

(per Figure 1)

**Figure 2. Total Supply Current versus Ambient Temperature, Supply Voltage**

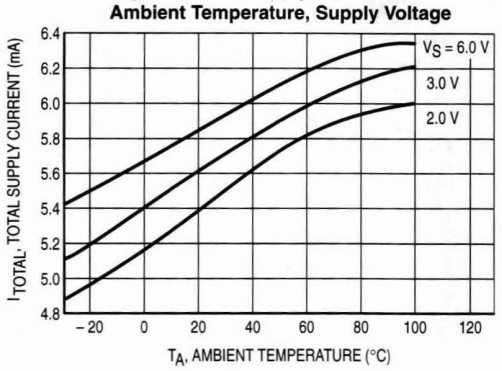



**Figure 3. Data Slicer On Output Current versus Ambient Temperature**

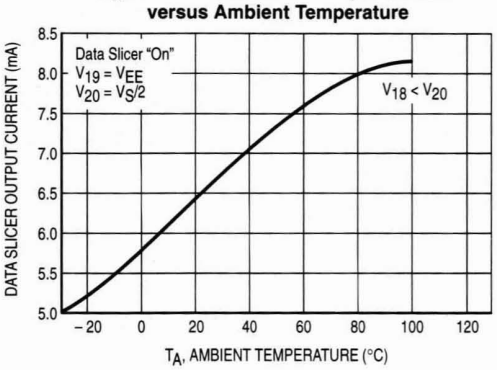



**Figure 4. Data Slicer On Output Current versus Ambient Temperature**

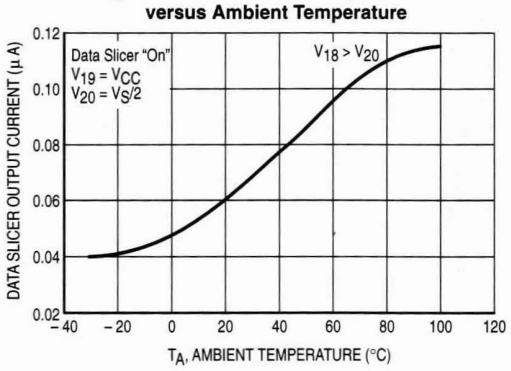



**Figure 5. Normalized Mixer Gain versus Ambient Temperature**

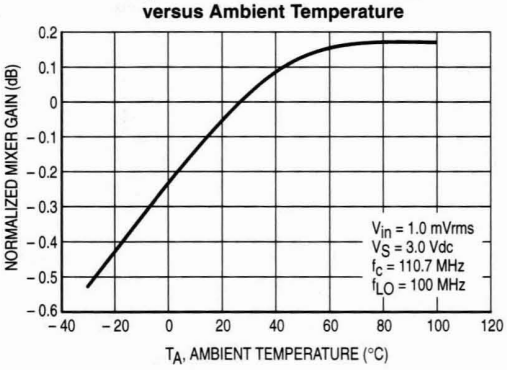



**Figure 6. Mixer RSSI Output Current versus Ambient Temperature, Mixer Input Level**

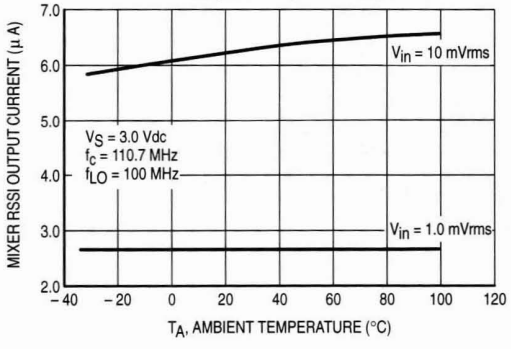
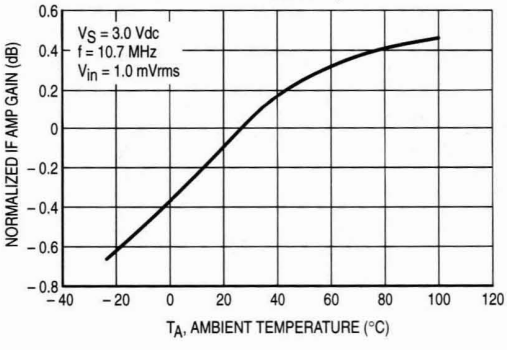



**Figure 7. Normalized IF Amp Gain versus Ambient Temperature**




8

## tTypical Performance Over Temperature

(per Figure 1)

**Figure 8. IF Amp RSSI Output Current versus Ambient Temperature, IF Input Level**

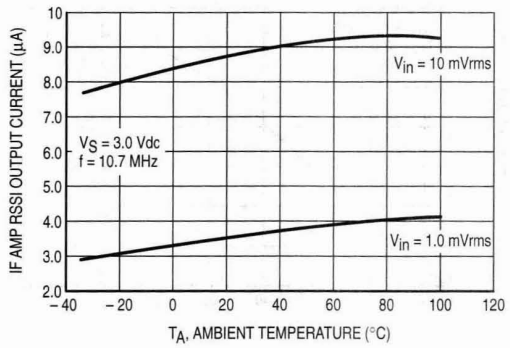



**Figure 9. Limiter Amp RSSI Output Current versus Ambient Temperature, Input Signal Level**

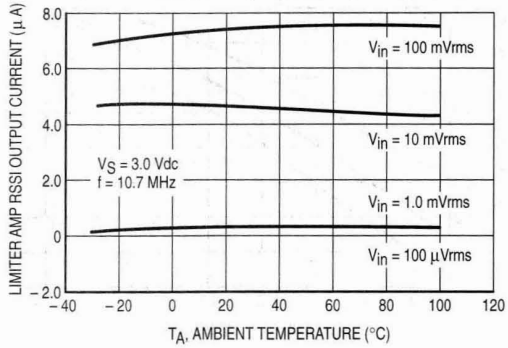



**Figure 10. Total RSSI Output Current versus Ambient Temperature (No Signal)**

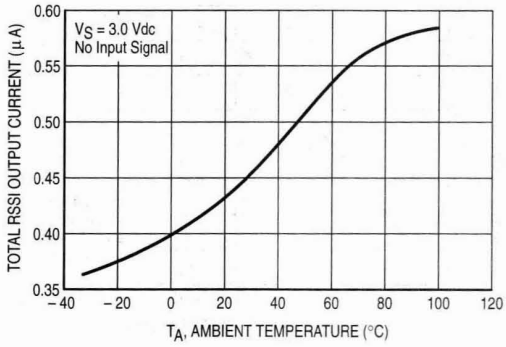
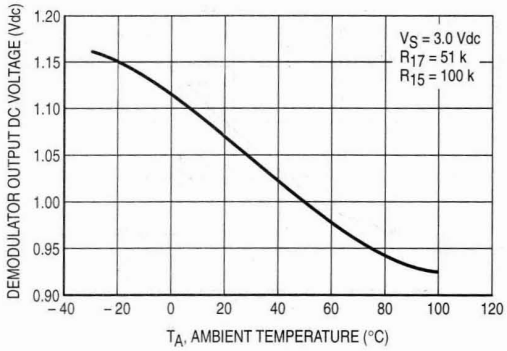



**Figure 11. Demodulator DC Voltage versus Ambient Temperature**




**SYSTEM LEVEL AC ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C; $V_S$ = 3.0 Vdc; $f_{RF}$ = 112 MHz; $f_{LO}$ = 122.7 MHz)

| Characteristic | Condition | Notes | Symbol | Typ | Unit |
|---|---|---|---|---|---|
| 12 dB SINAD Sensitivity:<br>Narrowband Application<br><br><br><br>Without Preamp<br>With Preamp | $f_{RF}$ = 112 MHz<br>$f_{mod}$ = 1.0 kHz<br>$f_{dev}$ = ±125 kHz<br>SINAD Curve<br>Figure 25<br>Figure 26 | 1 | – | <br><br><br><br>−101<br>−113 | dBm |
| Third Order Intercept Point<br><br>1.0 dB Comp. Point | $f_{RF1}$ = 112 MHz<br>$f_{RF2}$ = 112.1 MHz<br>$V_S$ = 3.5 Vdc<br>Figure 28 | 2 | IIP3<br><br>1.0 dB C.Pt. | −32<br><br>−39 | dBm |

**NOTES:** 1. Test Circuit & Test Set per Figure 24.
2. Test Circuit & Test Set per Figure 27.

## CIRCUIT DESCRIPTION

### General

The MC13158 is a low power single conversion wideband FM receiver incorporating a split IF. This device is designated for use as the backend in digital FM systems such as Digital European Cordless Telephone (DECT) and wideband data links with data rates up to 2.0 Mbps. It contains a mixer, oscillator, Received Signal Strength Indicator (RSSI), IF amplifier, limiting IF, quadrature detector, power down or enable function, and a data slicer with output off function. Further details are covered in the Pin Function Description which shows the equivalent internal circuit and external circuit requirements.

### Current Regulation/Enable

Temperature compensating voltage independent current regulators which are controlled by the enable pin (Pin 25) where "low" powers up and "high" powers down the entire circuit.

### Mixer

The mixer is a double–balanced four quadrant multiplier and is designed to work up to 500 MHz. It can be used in differential or in single ended mode by connecting the other input to the positive supply rail. The linear gain of the mixer is approximately 22 dB at 100 mVrms LO drive level. The mixer gain and noise figure have been emphasized at the expense of intermodulation performance. RSSI measurements are added in the mixer to extend the range to higher signal levels. The single–ended parallel equivalent input impedance of the mixer is Rp ~ 1.0 kΩ and Cp ~ 2.0 pF. The buffered output of the mixer is internally loaded resulting in an output impedance of 330 Ω.

### Local Oscillator

The on–chip transistor operates with crystal and LC resonant elements up to 220 MHz. Series resonant, overtone crystals are used to achieve excellent local oscillator stability. Third overtone crystals are used through about 65 to 70 MHz. Operation from 70 MHz up to 180 MHz is feasible using the on–chip transistor with a 5th or 7th overtone crystal. To enhance operation using an overtone crystal, the internal transistor bias is increased by adding an external resistor from Pin 29 to $V_{EE}$; however, with an external resistor the oscillator stays on during power down. Typically, –10 dBm of local oscillator drive is needed to adequately drive the mixer. With an external oscillator source, the IC can be operated up to 500 MHz.

### RSSI

The received signal strength indicator (RSSI) output is a current proportional to the log of the received signal amplitude. The RSSI current output is derived by summing the currents from the mixer, IF and limiting amplifier stages. An increase in RSSI dynamic range, particularly at higher input signal levels is achieved. The RSSI circuit is designed to provide typically 85 dB of dynamic range with temperature compensation.

Linearity of the RSSI is optimized by using external ceramic bandpass filters which have an insertion loss of 4.0 dB and 330 Ω source and load impedance. For higher data rates used in DECT and related applications, LC bandpass filtering is necessary to acquire the desired bandpass response; however, the RSSI linearity will require the same insertion loss.

### RSSI Buffer

The RSSI output current creates a voltage across an external resistor. A unity voltage–gain amplifier is used to buffer this voltage. The output of this buffer has an active pull–up but no pull–down, so it can also be used as a peak detector. The negative slew rate is determined by external capacitance and resistance to the negative supply.

### IF Amplifier

The first IF amplifier section is composed of three differential stages with the second and third stages contributing to the RSSI. This section has internal DC feedback and external input decoupling for improved symmetry and stability. The total gain of the IF amplifier block is approximately 40 dB at 10.7 MHz.

The fixed internal input impedance is 330 Ω. When using ceramic filters requiring source and loss impedances of 330 Ω, no external matching is necessary. Overall RSSI linearity is dependent on having total midband attenuation of 10 dB (4.0 dB insertion loss plus 6.0 dB impedance matching loss) for the filter. The output of the IF amplifier is buffered and the impedance is 330 Ω.

### Limiter

The limiter section is similar to the IF amplifier section except that five differential stages are used. The fixed internal input impedance is 330 Ω. The total gain of the limiting amplifier section is approximately 70 dB. This IF limiting amplifier section internally drives the quadrature detector section and it is also brought out on Pin 12.

### Quadrature Detector

The quadrature detector is a doubly balanced four quadrant multiplier with an internal 5.0 pF quadrature capacitor between Pins 12 and 13. An external capacitor may be added between these pins to increase the IF signal to the external parallel RLC resonant circuit that provides the 90 degree phase shift and drives the quadrature detector. A single pin (Pin 13) provides for the external LC parallel resonant network and the internal connection to the quadrature detector.

Internal low pass filter capacitors have been selected to control the bandwidth of the detector. The recovered signal is brought out by the inverting amplifier buffer. An external feedback resistor from the output (Pin 17) to the input of the inverting amplifier (Pin 15) controls the output amplitude; it is combined with another external resistor from the input to the negative supply (Pin 16) to set the output dc level. For a resistor ratio of 1, the DC level at the detector output is 2.0 $V_{BE}$ (see Figure 12). A small capacitor $C_{17}$ across the first resistor (from Pin 17 to 15) can be used to reduce the bandwidth.

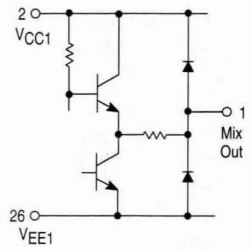
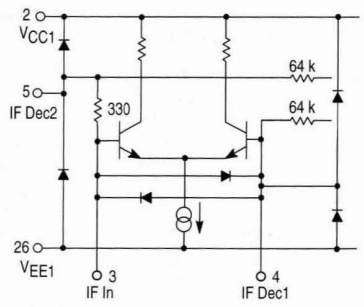
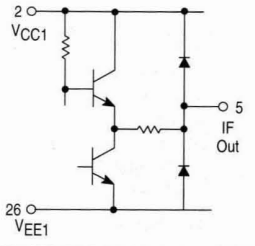
### Data Slicer

The data slicer is a comparator that is designed to square up the data signal. Across the data slicer inputs (Pins 18 and 20) are back to back diodes.

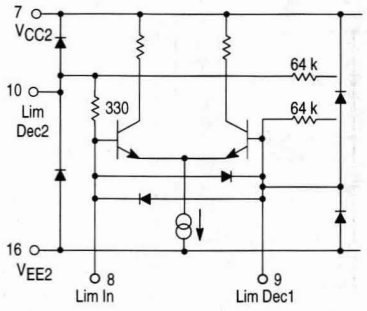
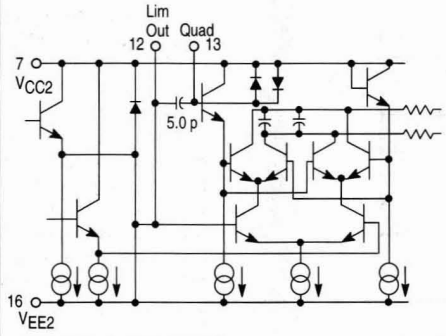
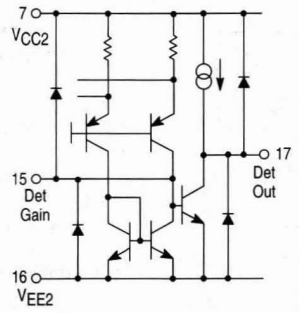
The recovered data signal from the quadrature detector can be DC coupled to the data slicer DS IN1 (Pin 18). In the application circuit shown in Figure 1 it will be centered at 2.0 $V_{BE}$ and allowed to swing ± $V_{BE}$. A capacitor is placed from DS IN2 (Pin 20) to $V_{EE}$. The size of this capacitor and the nature of the data signal determine how faithfully the data slicer shapes up the recovered signal. The time constant is short for large peak to peak voltage swings or when there is a change in DC level at the detector output. For small signal or for continuous bits of the same polarity which drift close to the threshold voltage, the time constant is longer.

A unique feature of the data slicer is that the inverting switching stages in the comparator are supplied through the emitter pin of the output transistor (Pin 22 – DS Gnd) to $V_{EE}$ rather than internally to $V_{EE}$. This is provided in order to reduce switching feedback to the front end. A control pin is provided to shut the data slicer output off (DS "off" – Pin 19). With DS "off" pin at $V_{CC}$ the data slicer output is shut off by shutting down the base drive to the output transistor. When a channel is being monitored to make an RSSI measurement, but not to collect data, the data output may be shut off to save current.

**PIN FUNCTION DESCRIPTION**

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 1 | Mix Out |  | **Mixer Output**<br>The mixer output impedance is 330 Ω; it matches to 10.7 MHz ceramic filters with 330 Ω input impedance. |
| 2 | $V_{CC1}$ | | **Supply Voltage ($V_{CC1}$)**<br>This pin is the $V_{CC}$ pin for the Mixer, Local Oscillator, and IF Amplifer. The operating supply voltage range is from 1.8 Vdc to 5.0 Vdc. In the PCB layout, the $V_{CC}$ trace must be kept as wide as possible to minimize inductive reactances along the trace; it is best to have it completely fill around the surface mount components and traces on the circuit side of the PCB. |
| 3 | IF In |  | **IF Input**<br>The input impedance at Pin 3 is 330 Ω. It matches the 330 Ω load impedance of a 10.7 MHz ceramic filter. Thus, no external matching is required. |
| 4 | IF Dec1 | | **IF DEC1 & DEC2**<br>IF decoupling pins. Decoupling capacitors should be placed directly at the pins to enhance stability. Two capacitors are decoupled to the RF ground $V_{CC1}$; one is placed between DEC1 & DEC2. |
| 5 | IF Dec2 | | |
| 6 | IF Out |  | **IF Output**<br>The output impedance is 330 Ω; it matches the 330 input resistance of a 10.7 MHz ceramic filter. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 7 | $V_{CC2}$ |  | **Supply Voltage ($V_{CC2}$)**<br>This pin is $V_{CC}$ supply for the Limiter, Quadrature Detector, data slicer and RSSI buffer circuits. In the application PC board this pin is tied to a common $V_{CC}$ trace with $V_{CC1}$.<br><br>**Limiter Input**<br>The limiter input impedance is 330 Ω.<br><br>**Limiter Decoupling**<br>Decoupling capacitors are placed directly at these pins and to $V_{CC}$ (RF ground). Use the same procedure as in the IF decoupling. |
| 8 | Lim In | | |
| 9 | Lim Dec1 | | |
| 10 | Lim Dec2 | | |
| 11,14, 27 & 28 | N/C | | **No Connects**<br>There is no internal connection to these pins; however it is recommended that these pins be connected externally to $V_{CC}$ (RF ground). |
| 12 | Lim Out |  | **Limiter Output**<br>The output impedance is low. The limiter drives a quadrature detector circuit with in–phase and quadrature phase signals.<br><br>**Quadrature Detector Circuit**<br>The quadrature detector is a doubly balanced four–quadrant multiplier with an internal 5.0 pF capacitor between Pins 12 and 13. An external capacitor may be added to increase the IF signal to Pin 13. The quadrature detector pin is provided to connect the external RLC parallel resonant network which provides the 90 degree phase shift and drives the quadrature detector. |
| 13 | Quad | | |
| 15 | Det Gain |  | **Detector Buffer Amplifier**<br>This is an inverting amplifier. An external feedback resistor from Pin 17 to 15, (the inverting input) controls the output amplitude; another resistor from Pin 15 to the negative supply (Pin 16) sets the DC output level. A 1:1 resistor ratio sets the output DC level at two $V_{BE}$ with respect to $V_{EE}$. A small capacitor from Pin 17 to 15 can be used to set the bandwidth.<br><br>**Supply Ground ($V_{EE2}$)**<br>In the PCB layout, the ground pins (also applies to Pin 26) should be connected directly to chassis ground. Decoupling capacitors to $V_{CC}$ should be placed directly at the ground pins. |
| 17 | Det Out | | |
| 16 | $V_{EE2}$ | | |

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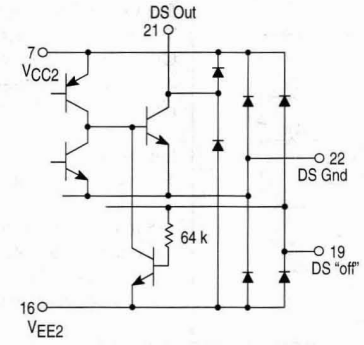
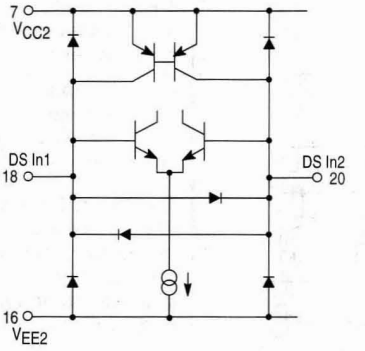
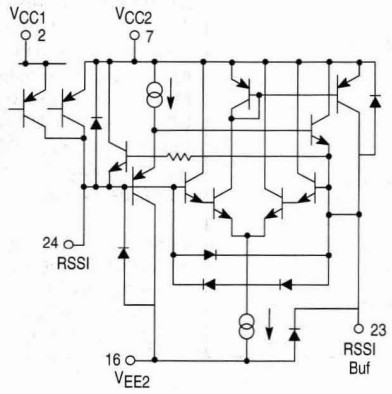
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 19<br><br>21<br><br>22 | DS<br>"off"<br><br>DS<br>Out<br><br>DS<br>Gnd |  | **Data Slicer Off**<br>The data output may be shut off to save current by placing DS "off" (Pin 19) at $V_{CC}$.<br><br>**Data Slicer Output**<br>In the application example a 10 kΩ pull–up resistor is connected to the collector of the output transistor at Pin 21.<br><br>**Data Slicer Ground**<br>All the inverting switching stages in the comparator are supplied through the emitter pin of the output transistor (Pin 22) to ground rather than internally to $V_{EE}$ in order to reduce switching feedback to the front end. |
| 18<br><br>20 | DS<br>In1<br><br>DS<br>In2 |  | **Data Slicer Inputs**<br>The data slicer has differential inputs with back to back diodes across them. The recovered signal is DC coupled to DS IN1 (Pin 18) at nominally $V_{18}$ with respect to $V_{EE}$; thus, it will maintain $V_{18} \pm V_{BE}$ at Pin 18. DS IN2 (Pin 20) is AC coupled to $V_{EE}$. The choice of coupling capacitor is dependent on the nature of the data signal. For small signal or continuous bits of the same polarity, the response time is relatively large. On the other hand, for large peak to peak voltage swings or when the DC level at the detector output changes, the response time is short. See the discussion in the application section for external circuit design details. |
| 23<br><br>24 | RSSI<br>Buf<br><br>RSSI |  | **RSSI Buffer**<br>A unity gain amplifier is used to buffer the voltage at Pin 24 to 23.The output of the unity gain buffer (Pin 23) has an active pull up but no pull down. An external resistor is placed from Pin 23 to $V_{EE}$ to provide the pull down.<br><br>**RSSI**<br>The RSSI output current creates a voltage drop across an external resistor from Pin 24 to $V_{EE}$. The maximum RSSI current is 26 μA; thus, the maximum RSSI voltage using a 100 kΩ resistor is approximately 2.6 Vdc. Figure 22 shows the RSSI Output Voltage versus Input Signal Level in the application circuit.<br><br>The negative slew rate is determined by an external capacitor and resistor to $V_{EE}$ (negative supply). The RSSI rise and fall times for various RF input signal levels and $R_{24}$ values without the capacitor, $C_{24}$ are displayed in Figure 24. This is the maximum response time of the RSSI. |

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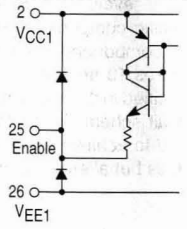
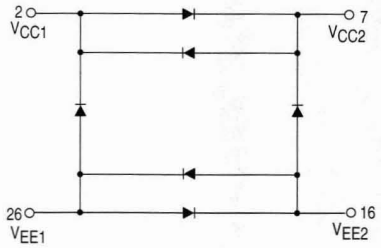
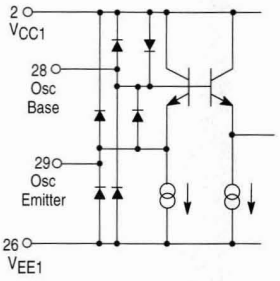
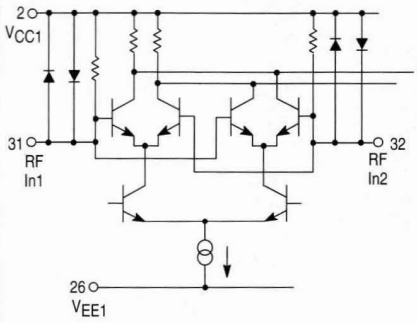
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 25<br><br><br><br><br><br>26 | Enable<br><br><br><br><br><br>$V_{EE1}$ |  | **Enable**<br>The IC regulators are enabled by placing this pin at $V_{EE}$. |
| | |  | **$V_{CC}$ and $V_{EE}$ ESD Protection**<br>ESD protection diodes exist between the $V_{CC}$ and $V_{EE}$ pins. It is important to note that significant differences in potential (> 0.5 $V_{BE}$) between the two $V_{CC}$ pins or between the $V_{EE}$ pins can cause these structures to start to conduct, thus compromising isolation between the supply busses. $V_{CC1}$ & $V_{CC2}$ should be maintained at the same DC potential, as should $V_{EE1}$ & $V_{EE2}$. |
| 28<br>Osc Base<br><br>29<br>Osc Emitter | |  | **Oscillator Base**<br>This pin is connected to the base lead of the common collector transistor. Since there is no internal bias resistor to the base, $V_{CC}$ is applied through an external choke or coil.<br><br>**Oscillator Emitter**<br>This pin is connected to the emitter lead; the emitter is connected internally to a current source of about 200 μA. Additional emitter current may be obtained by connecting an external resistor to $V_{EE}$; $I_E = V_{29}/R_{29}$.<br><br>Details of circuits using overtone crystal and LC varactor controlled oscillators are discussed in the application section. |
| 31<br>Mix In1<br><br>32<br>Mix In2 | |  | **Mixer Inputs**<br>The parallel equivalent differential input impedance of the mixer is approximately 2.0 kΩ in parallel with 1.0 pF. This equates to a single ended input impedance of 1.0 kΩ in parallel with 2.0 pF.<br><br>The application circuit utilizes a SAW filter having a differential output that requires a 2.0 kΩ II 2.0 pF load. Therefore, little matching is required between the SAW filter and the mixer inputs. This and alternative circuits are discussed in more detail in the application section. |

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## APPLICATIONS INFORMATION

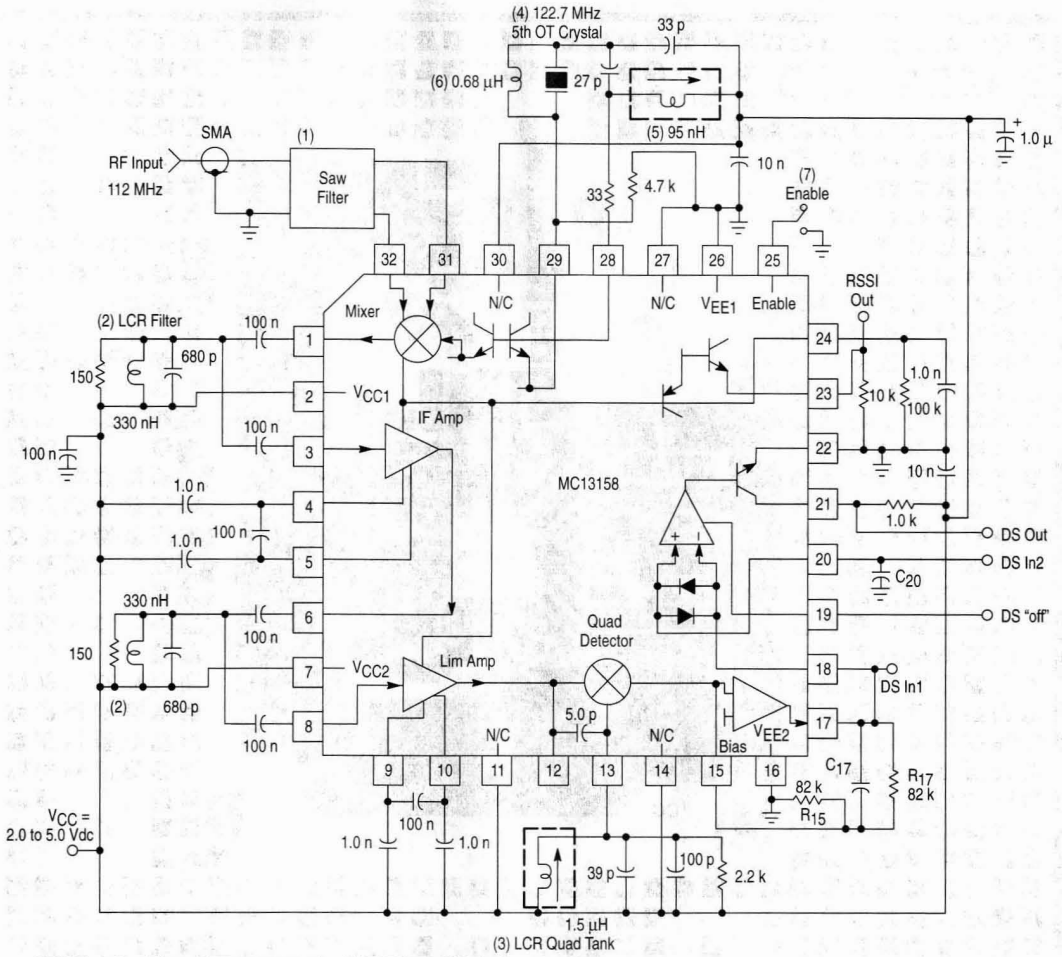
### Evaluation PC Board

The evaluation PCB is very versatile and is intended to be used across the entire useful frequency range of this device. The center section of the board provides an area for attaching all SMT components to the circuit side and radial leaded components to the component ground side (see Figures 29 and 30). Additionally, the peripheral area surrounding the RF core provides pads to add supporting and interface circuitry as a particular application dictates. This evaluation board will be discussed and referenced in this section.

### Component Selection

The evaluation PC board is designed to accommodate specific components, while also being versatile enough to use components from various manufacturers and coil types. Figures 13 and 14 show the placement for the components specified in the application circuit (Figure 12). The application circuit schematic specifies particular components that were used to achieve the results shown in the typical curves and tables but alternate components should give similar results.

**Figure 12. Application Circuit**




**NOTES:** 1. Saw Filter – Siemens part number Y6970M(5 pin SIP plastic package).
2. An LCR filter reduces the broadband noise in the IF; ceramic filters may be used for data rates under 500 kHz. 4.0 dB insertion loss filters optimize the linearity of RSSI.
3. The quadrature tank components are chosen to optimize linearity of the recovered signal while maintaining adequate recovered signal level. 1.5 µH 7.0 mm variable shielded inductor: Toko part # 292SNS–T1373Z. The shunt resistor is approximately equal to Q(2πfL), where Q ~ 18 (3.0 dB BW = 600 kHz).
4. The local oscillator circuit utilizes a 122.7 MHz, 5th overtone, series resonant crystal specified with a frequency tolerance of 25 PPM, ESR of 120 Ω max. The oscillator configuration is an emitter coupled butler.
5. The 95 NH (Nominal) inductor is a 7.0 mm variable shielded inductor: Coilcraft part # 150–04J08S or equivalent.
6. 0.68 µH axial lead chokes (molded inductor ): Coilcraft part # 90–11.
7. To enable the IC, Pin 25 is taken to $V_{EE}$. The external pull down resistor at Pin 29 could be linked to the enable function; otherwise if it is taken to $V_{EE}$ as shown, it will keep the oscillator biased at about 500 µA depending on the $V_{CC}$ level.
8. The other resistors and capacitors are surface mount components.

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Figure 13. Circuit Side Component Placement

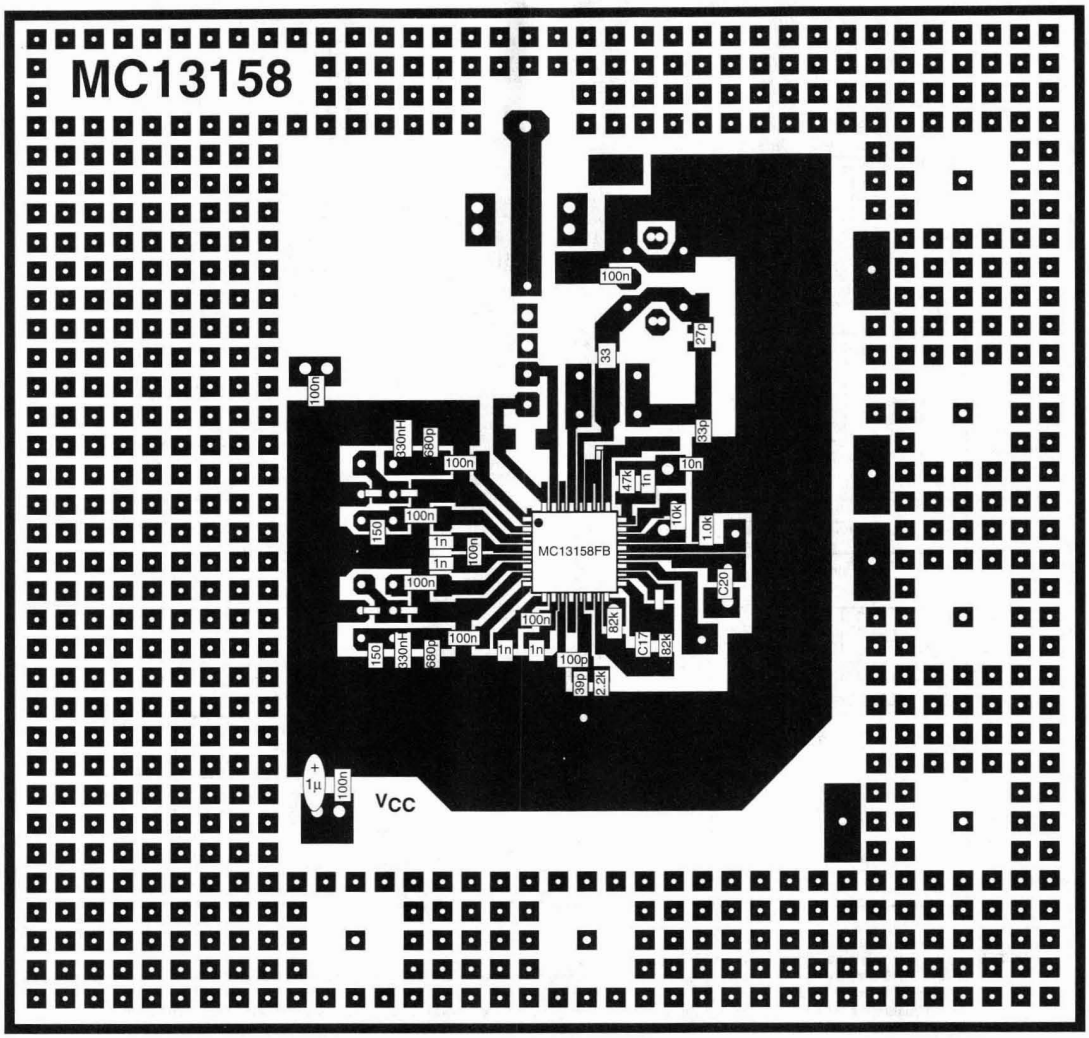
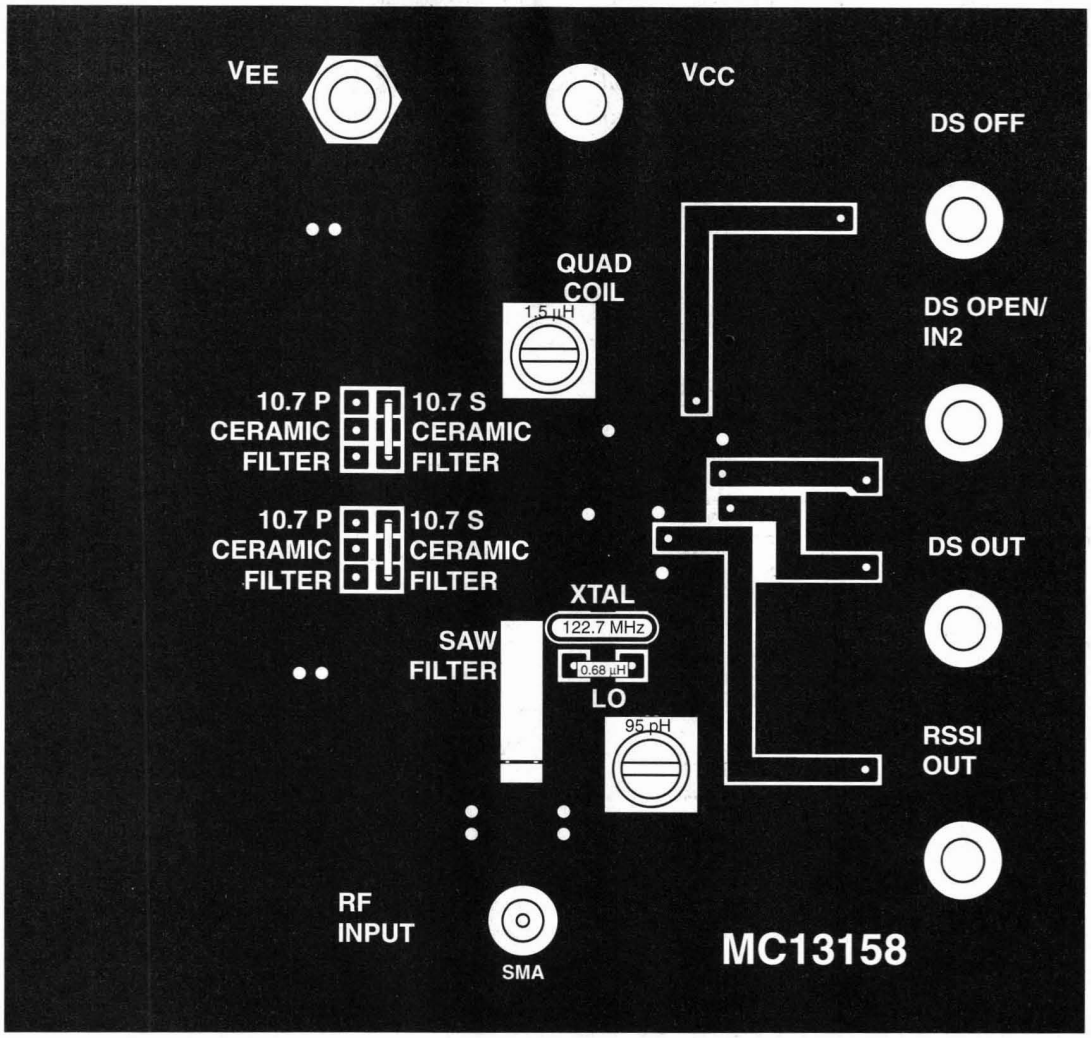


Figure 14. Ground Side Component Placement

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**Input Matching/Components**

It is desirable to use a SAW filter before the mixer to provide additional selectivity and adjacent channel rejection. In a wideband system the primary sensitivity of the receiver backend may be achieved before the last mixer. Bandpass filtering in the limiting IF is costly and difficult to achieve for bandwidths greater than 280 kHz.

The SAW filter should be selected to easily interface with the mixer differential input impedance of approximately 2.0 kΩ in parallel with 1.0 pF. The PC board is dedicated to the Siemens SAW filter (part number Y6970M); the part is designed for DECT at 112 MHz 1st IF frequency. It is designed for a load impedance of 2.0 kΩ in parallel with 2.0 pF; thus, no or little input matching is required between the SAW filter and the mixer.

The Siemens SAW filter has an insertion loss of typically 10 dB and a 3.0 dB bandwidth of 1.0 MHz. The relatively high insertion loss significantly contributes to the system noise and a filter having lower insertion loss would be desirable. In existing low loss SAW filters, the required load impedance is 50 Ω; thus, interface matching between the filter and the mixer will be required. Figure 15 is a table of the single–ended mixer input impedance. A careful noise analysis is necessary to determine the secondary contribution to system noise.

**Figure 15. Mixer Input Impedance**
(Single–ended)

| f (MHz) | Rs (Ω) | Xs (Ω) | Rp (Ω) | Xp (Ω) | Cp (pF) |
|---|---|---|---|---|---|
| 50 | 930 | −350 | 1060 | −2820 | 1.1 |
| 100 | 480 | −430 | 865 | −966 | 1.6 |
| 150 | 270 | −400 | 860 | −580 | 1.8 |
| 200 | 170 | −320 | 770 | −410 | 1.9 |
| 250 | 130 | −270 | 690 | −330 | 1.85 |
| 300 | 110 | −250 | 680 | −300 | 1.8 |
| 400 | 71 | −190 | 580 | −220 | 1.8 |
| 500 | 63 | −140 | 370 | −170 | 1.9 |
| 600 | 49 | −110 | 300 | −130 | 2.0 |

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**System Noise Considerations**

The system block diagram in Figure 16 shows the cascaded noise stages contributing to the system noise; it represents the application circuit in Figure 12 and a low noise preamp using a MRF941 transistor (see Figure 17). The preamp is designed for a conjugately matched input and output at 2.0 Vdc $V_{CE}$ and 3.0 mAdc $I_C$. S–parameters at 2.0 V, 3.0 mA and 100 MHz are:

S11 = 0.86, –20
S21 = 9.0, 164
S12 = 0.02, 79
S22 = 0.96, –12

The bias network sets $V_{CE}$ at 2.0 V and $I_C$ at 3.0 mA for $V_{CC}$ = 3.0 to 3.5 Vdc. The preamp operates with 18 dB gain and 2.7 dB noise figure.

In the cascaded noise analysis the system noise equation is:

$$Fsystem = F1 + [(F2–1)/G1] + [(F3–1)]/[(G1)(G2)]$$

where:

F1 = the Noise Factor of the Preamp
G1 = the Gain of the Preamp
F2 = the Noise factor of the SAW Filter
G2 = the Gain of the SAW Filter
F3 = the Noise factor of the Mixer

**Note:** the proceeding terms are defined as linear relationships and are related to the log form for gain and noise figure by the following:

$F = \log^{-1}[(NF \text{ in dB})/10]$ and similarly

$G = \log^{-1}[(Gain \text{ in dB})/10]$

The noise figure and gain measured in dB are shown in the system block diagram. The mixer noise figure is typically 14 dB and the SAW filter adds typically 10 dB insertion loss. Addition of a low noise preamp having a 18 dB gain and 2.7 dB noise figure not only improves the system noise figure but it increases the reverse isolation from the local oscillator to the antenna input at the receiver. Calculating in terms of gain and noise factor yields the following:

F1 = 1.86; G1 = 63.1
F2 = 10; G2 = 0.1
F3 = 25.12

Thus, substituting in the equation for system noise factor:

Fsystem = 5.82; NFsystem = 7.7 dB

**Figure 16. System Block Diagram for Noise Analysis**

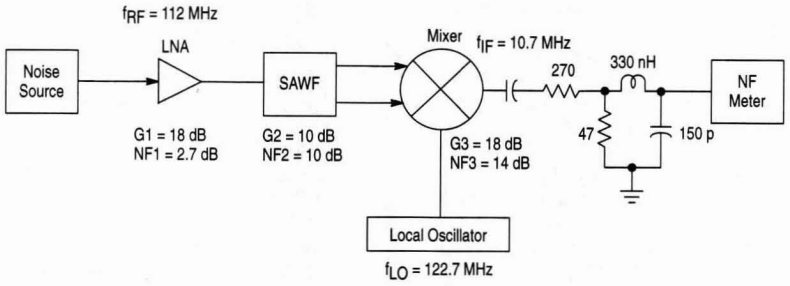
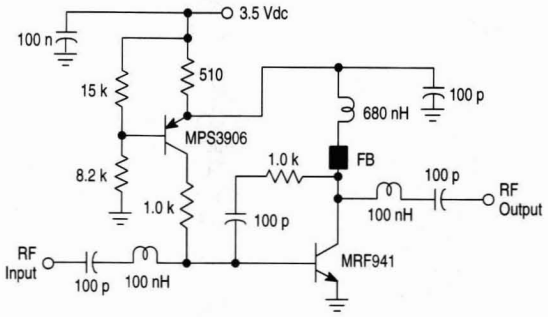



**Figure 17. 112 MHz LNA**




## LOCAL OSCILLATORS

### VHF Applications

The on–chip grounded collector transistor may be used for HF and VHF local oscillator with higher order overtone crystals. The local oscillator in the application circuit (Figure 12) shows a 5th overtone oscillator at 122.7 MHz. This circuit uses a Butler overtone oscillator configuration. The amplifier is an emitter follower. The crystal is driven from the emitter and is coupled to the high impedance base through a capacitive tap network. Operation at the desired overtone frequency is ensured by the parallel resonant circuit formed by the variable inductor and the tap capacitors and parasitic capacitances of the on–chip transistor and PC board. The variable inductor specified in the schematic could be replaced with a high tolerance, high Q ceramic or air wound surface mount component if the other components have tight enough tolerances. A variable inductor provides an adjustment for gain and frequency of the resonant tank ensuring lock up and start–up of the crystal oscillator. The overtone crystal is chosen with ESR of typically 80 Ω and 120 Ω maximum; if the resistive loss in the crystal is too high the performance of oscillator may be impacted by lower gain margins.

A series LC network to ground (which is $V_{CC}$) is comprised of the inductance of the base lead of the on–chip transistor and PC board traces and tap capacitors. Parasitic oscillations often occur in the 200 to 800 MHz range. A small resistor is placed in series with the base (Pin 28) to cancel the negative resistance associated with this undesired mode of oscillation. Since the base input impedance is so large a small resistor in the range of 27 to 68 Ω has very little effect on the desired Butler mode of oscillation.

The crystal parallel capacitance, $C_O$, provides a feedback path that is low enough in reactance at frequencies of 5th overtones or higher to cause trouble. $C_O$ has little effect near resonance because of the low impedance of the crystal motional arm ($R_m$–$L_m$–$C_m$). As the tunable inductor which forms the resonant tank with the tap capacitors is tuned "off" the crystal resonant frequency it may be difficult to tell if the oscillation is under crystal control. Frequency jumps may occur as the inductor is tuned. In order to eliminate this behavior an inductor, $L_O$, is placed in parallel with the crystal. $L_O$ is chosen to be resonant with the crystal parallel capacitance, $C_O$, at the desired operation frequency. The inductor provides a feedback path at frequencies well below resonance; however, the parallel tank network of the tap capacitors and tunable inductor prevent oscillation at these frequencies.

### IF Filtering/Matching

In wideband data systems the IF bandpass needed is greater than can be found in low cost ceramic filters operating at 10.7 MHz. It is necessary to bandpass limit with LC networks or series–parallel ceramic filter networks. Murata offers a series–parallel resonator pair (part number

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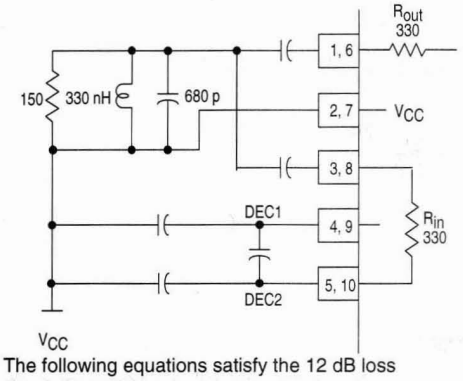
KMFC545) with a 3.0 dB bandwidth of ± 325 kHz and a maximum insertion loss of 5.0 dB. The application PC board is laid out to accommodate this filter pair (a filter pair is used at both locations of the split IF). However, even using a series parallel ceramic filter network yields only a maximum bandpass of 650 kHz. In some applications a wider band IF bandpass is necessary.

A simple LC network yields a bandpass wider than the SAW filter but it does reduce an appreciable amount of wideband IF noise. In the application circuit an LC network is specified using surface mount components. The parallel LC components are placed from the outputs of the mixer and IF amplifier to the $V_{CC}$ trace; internal 330 loads are connected from the mixer and IF amplifier outputs to DEC2 (Pin 5 and 10 respectively).This loads the outputs with the optimal load impedance but creates a low insertion loss filter. An external shunt resistor may be used to widen the bandpass and to acquire the 10 dB composite loss necessary to linearize the RSSI output. The equivalent circuit is shown in Figure 18.

**Figure 18. IF LCR Filter**




The following equations satisfy the 12 dB loss (1:4 resistive ratio):

$$(Rext)(330)/(Rext + 330) = Requivalent$$
$$Requivalent/(Requivalent + 330) = 1/4$$

Solve for Requivalent:

$$4(Requivalent) = Requivalent + 330$$
$$3(Requivalent) = 330$$
$$Requivalent = 110$$

Substitute for Requivalent and solve for Rext:

$$330(Rext) = 110(Rext) + (330)(110)$$
$$Rext = (330)(110)/220$$
$$Rext = 165\ \Omega$$

The IF is 10.7 MHz although any IF between 10 to 20 MHz could be used. The value of the coil is lowered from that used in the quadrature circuit because the unloaded Q must be maintained in a surface mount component. A standard value component having an unloaded Q = 100 at 10.7 MHz is 330 nH; therefore the capacitor is 669 pF. Standard values have been chosen for these components;

$Rext = 150\ \Omega$
$C = 680$ pF
$L = 330$ nH

Computation of the loaded Q of this LCR network is

$$Q = Requivalent/X_L$$

where: $X_L = 2\pi fL$ and Requivalent is 103 Ω

Thus, $Q = 4.65$

The total system loss is

$$20 \log (103/433) = -12.5 \text{ dB}$$

**Quadrature Detector**

The quadrature detector is coupled to the IF with an internal 5.0 pF capacitor between Pins 12 and 13. For wideband data applications, the drive to the detector can be increased with an additional external capacitor between these pins; thus, the recovered signal level output is increased for a given bandwidth

The wideband performance of the detector is controlled by the loaded Q of the LC tank circuit. The following equation defines the components which set the detector circuit's bandwidth:

$$Q = R_T/X_L \quad [1]$$

where $R_T$ is the equivalent shunt resistance across the LC Tank

$X_L$ is the reactance of the quadrature inductor at the IF frequency ($X_L = 2\pi fL$).

The inductor and capacitor are chosen to form a resonant LC tank with the PCB and parasitic device capacitance at the desired IF center frequency as predicted by

$$f_c = [2\pi\ (LC_p)^{1/2}]^{-1} \quad [2]$$

where L is the parallel tank inductor $C_p$ is the equivalent parallel capacitance of the parallel resonant tank circuit.

The following is a design example for a wideband detector at 10.7 MHz and a loaded Q of 18. The loaded Q of the quadrature detector is chosen somewhat less than the Q of the IF bandpass. For an IF frequency of 10.7 MHz and an IF bandpass of 600 kHz, the IF bandpass Q is approximately 6.4.

**Example:**

Let the external Cext = 139 pF. (The minimum value here should be much greater than the internal device and PCB parasitic capacitance, Cint ≈ 3.0 pF). Thus, $C_p$ = Cint + Cext = 142 pF.

Rewrite equation (2) and solve for L:

$$L = (0.159)^2/(C_p f c^2)$$

$L = 1.56$ μH; Thus, a standard value is choosen:

$L = 1.56$ μH (tunable shielded inductor)

The value of the total damping resistor to obtain the required loaded Q of 18 can be calculated by rearranging equation (1):

$$R_T = Q(2\pi fL)$$
$$R_T = 18(2\pi)(10.7)(1.5) = 1815\ \Omega$$

The internal resistance, Rint at the quadrature tank Pin 13 is approximately 13 kΩ and is considered in determining the external resistance, Rext which is calculated from

$$Rext = ((R_T)(Rint))/(Rint - R_T)$$

$$Rext = 2110; \text{ Thus, choose the standard value:}$$

$$Rext = 2.2\ k\Omega$$

It is important to set the DC level of the detector output at Pin 17 to center the peak to peak swing of the recovered signal. In the equivalent internal circuit shown in the Pin Function Description, the reference voltage at the positive terminal of the inverting op amp buffer amplifier is set at 1.0 $V_{BE}$. The detector DC level, $V_{17}$ is determined by the following equation:

$$V_{17} = [((R_{15}/R_{17}) + 1)/(R_{15}/R_{17})]\ V_{BE}$$

Thus, for a 1:1 ratio of $R_{15}/R_{17}$, $V_{17}$ = 2.0 $V_{BE}$ = 1.4 Vdc. Similarly for a 2:1, $V_{17}$ = 1.5 $V_{BE}$ = 1.05 Vdc; and for 3:1, $V_{17}$ = 1.33 $V_{BE}$ = 0.93 Vdc.

Figure 19 shows the detector "S–Curves", in which the resistor ratio is varied while maintaining a constant gain ($R_{17}$ is held at 62 k). $R_{15}$ is 62 k for a 1:1 ratio; while $R_{15}$ = 120 k and 180 k to produce the 2:1 and 3:1 ratios. The IF signal into the detector is swept ± 500 kHz about the 10.7 MHz IF center frequency. The resulting curve show how the resistor ratio and the supply voltage effects the symmetry of the "S–curve" (Figure 21 Test Setup). For the 3:1 and 2:1 ratio, symmetry is maintained with $V_S$ from 2.0 to 5.0 Vdc; however, for the 1:1 ratio, symmetry is lost at 2.0 Vdc.

**Figure 19. Detector Output Voltage versus Frequency Deviation**

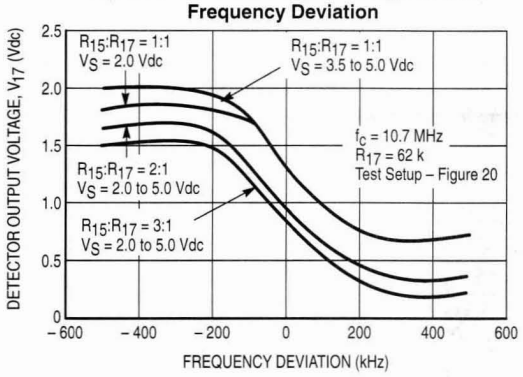
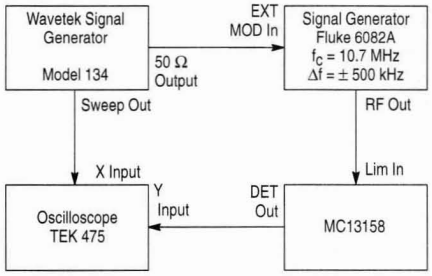



**Figure 20. Demodulator "S–Curve" Test Setup**




**Data Slicer Circuit**

$C_{20}$ at the input of the data slicer is chosen to maintain a time constant long enough to hold the charge on the capacitor for the longest strings of bits at the same polarity. For a data rate at 576 kHz a bit stream of 15 bits at the same polarity would equate to an apparent data rate of approximately 77 kbps or 38 kHz. The time constant would be approximately 26 µs. The following expression equates the time constant, t, to the external components:

$$t = 2\pi\ (R_{18})(C_{20})$$

Solve for $C_{20}$:

$$C_{20} = t/2\pi\ (R_{18})$$

where the effective resistance $R_{18}$ is a complex function of the demodulator feedback resistance and the data slicer input circuit. In the data input network the back to back diodes form a charge and discharge path for the capacitor at Pin 20; however, the diodes create a non–linear response. This resistance is loaded by the ß, beta of the detector output transistor; beta =100 is a typical value (see Figure 21). Thus, the apparent value of the resistance at Pin 18 (DS IN1) is approximately equal to:

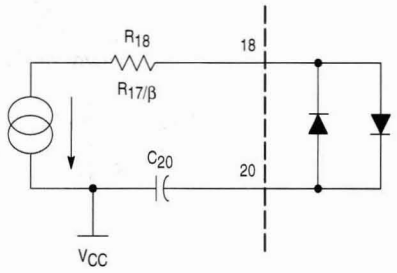
$$R_{18} \sim R_{17}/100$$

where $R_{17}$ is 82 kΩ, the feedback resistor from Pin 17 to 15. Therefore, substituting for $R_{18}$ and solving for $C_{20}$:

$$C_{20} = 15.9\ (t)/R_{17} = 5.04\ nF$$

The closest standard value is 4.7 nF.

**Figure 21. Data Slicer Equivalent Input Circuit**

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## SYSTEM PERFORMANCE DATA

### RSSI

In Figure 22, the RSSI versus RF Input Level shows the linear response of RSSI over a 65 dB range but it has extended capability over 80 dB from −80 dBm to +10 dBm. The RSSI is measured in the application circuit (Figure 12) in which a SAW filter is used before the mixer; thus, the overall sensitivity is compromised for the sake of selectivity. The curves are shown for three filters having different bandwidths:

1) LCR Filter with 2.3 MHz 3.0 dB BW (Circuit and Component Placement is shown in Figure 12)
2) Series–Parallel Ceramic Filter with 650 kHz 3.0 dB BW (Murata Part # KMFC–545)
3) Ceramic Filter with 280 kHz 3.0 dB BW.

**Figure 22. RSSI Output Voltage versus Signal Input Level**

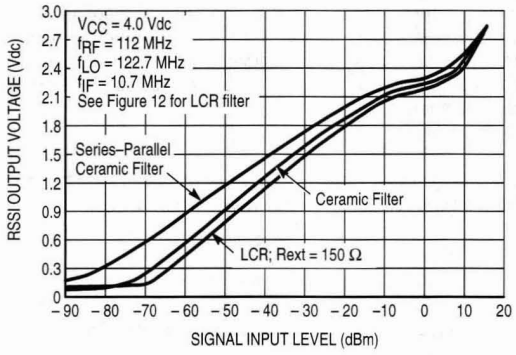
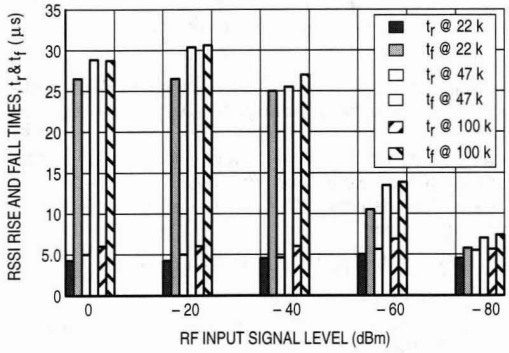



**Figure 23. RSSI Output Rise and Fall Times versus RF Input Signal Level**




### SINAD Performance

Figure 24 shows a test setup for a narrowband demodulator output response in which a C–message filter and an active de–emphasis filter is used following the demodulator. The input is matched using a 1:4 impedance transformer. The SINAD performance is shown in Figure 25 with no preamp and in Figure 26 with a preamp (Preamp – Figure 16). The 12 dB SINAD sensitivity is –101 dBm with no preamp and –113 dBm with the preamp.

**Figure 24. Test Setup for Narrowband SINAD**

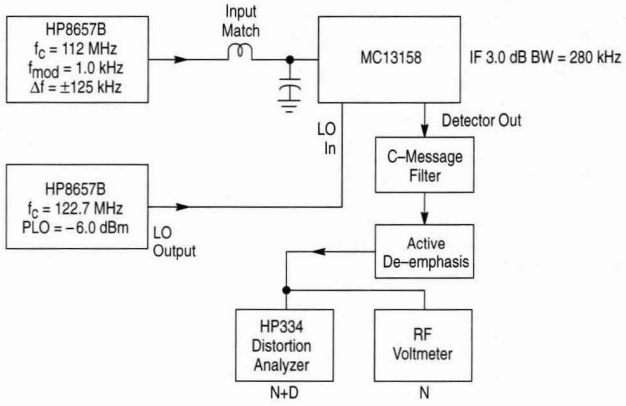



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**Figure 25. S+N+D, N+D, N versus Input Signal Level (without preamp)**

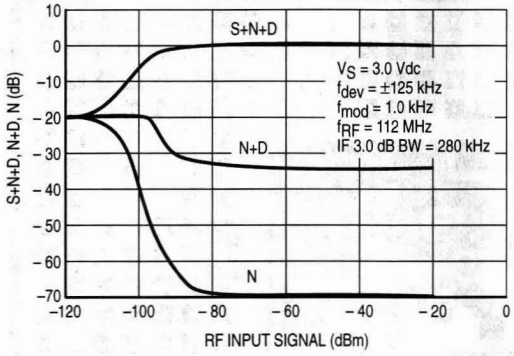


**Figure 26. S+N+D, N+D, N versus Input Signal Level (with preamp)**

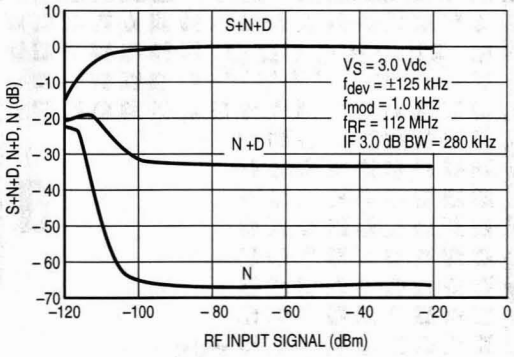


**Figure 27. Input IP3, 1.0 dB Compression Pt. Test Setup**

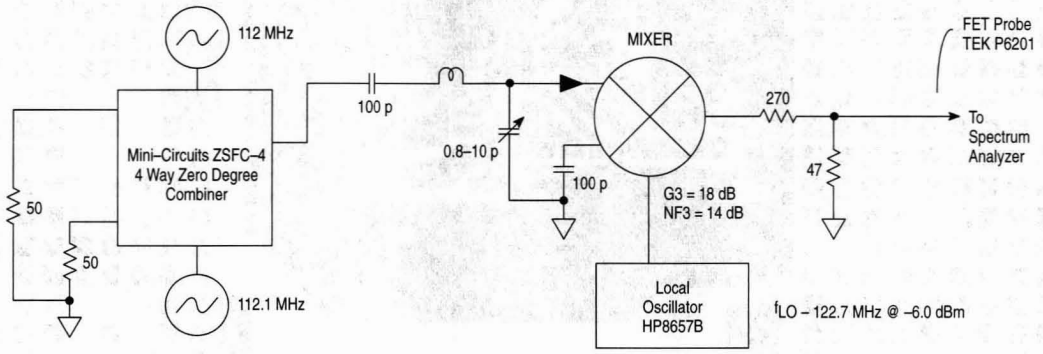


**Figure 28. –1.0 dB Compression Pt. and Input Third Order Intercept**

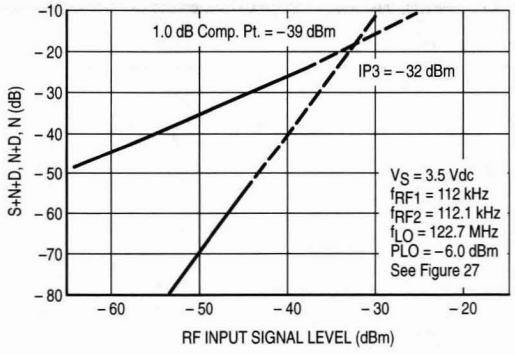
1.0 dB Comp. Pt. = –39 dBm
IP3 = –32 dBm
$V_S$ = 3.5 Vdc
$f_{RF1}$ = 112 kHz
$f_{RF2}$ = 112.1 kHz
$f_{LO}$ = 122.7 MHz
PLO = –6.0 dBm
See Figure 27
S+N+D, N+D, N (dB)
RF INPUT SIGNAL LEVEL (dBm)

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Figure 29. Circuit Side View

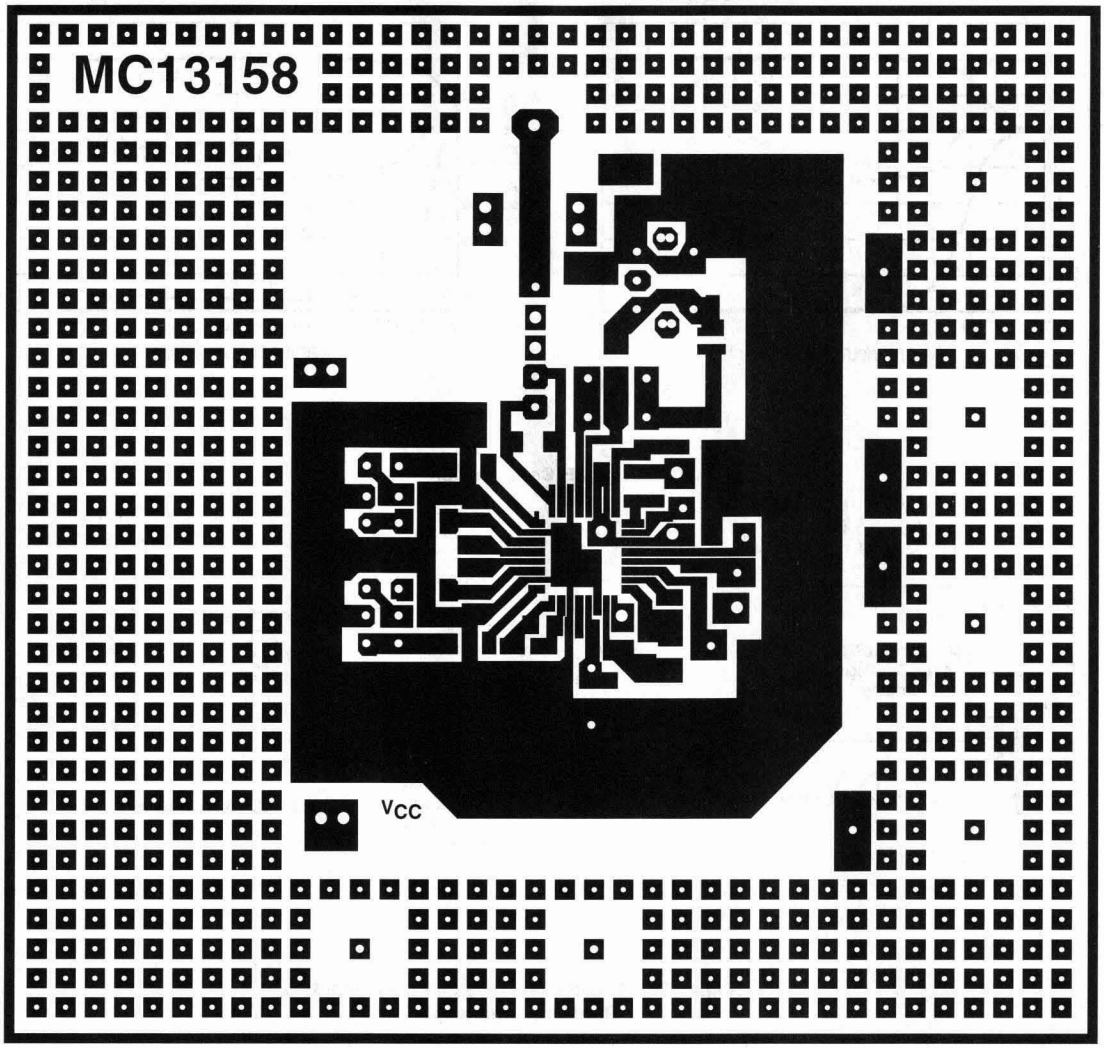
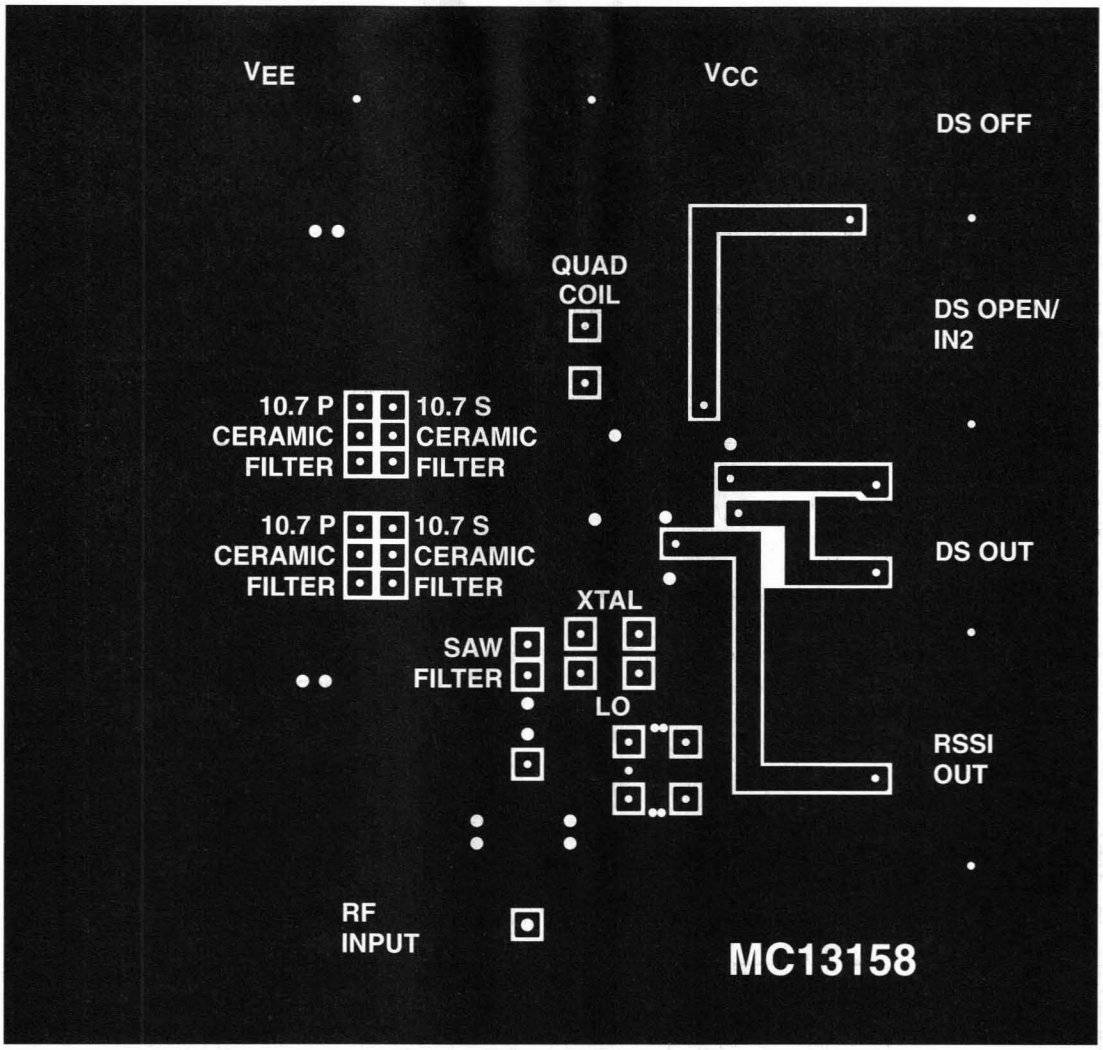


Figure 30. Ground Side View



MOTOROLA

# MC13159

*Advance Information*

## Wideband FM IF Amp

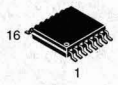
**WIDEBAND FM IF SUBSYSTEM FOR PHS AND DIGITAL APPLICATIONS**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13159 is a wideband FM IF subsystem that is designed for high performance data and digital applications. Excellent high frequency performance is achieved, with low cost, through the use of Motorola's RF bipolar process. The MC13159 includes a mixer, Local Oscillator Buffer amplifier, IF amplifier, Limiter amplifier and RSSI functions. The mixer is useful for 240 MHz input used in a single–ended/balanced differential configuration. The IF and Limiter amplifier are separated for using the external filter in series or connecting directly by an external capacitor. RSSI output is derived by summing the output of both IF and Limiter sections. An enable control is provided to power down the IC for power management in battery operated applications.

Applications are suitable for PHS, DECT, PDC, GSM, PCS, wideband wireless data links and other battery operated radio systems.

- Designed for PHS Applications
- 2.7 to 5.5 V Operating Voltage
- Low Drain Current: 5.5 mA (Typ)
- Wide Input Dynamic Range of Mixer (Maximum –16 dBm Input)
- Enable Function for Power Down Mode
- Over 80 dB of RSSI Dynamic Range (AC Coupling Between IF Amplifier and Limiter Amplifier)
- Low External Component Count

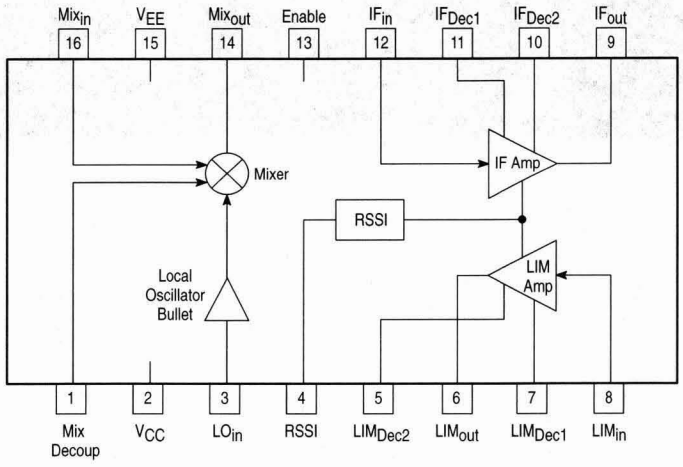



**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948F
(TSSOP–16L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13159DTB | $T_A$ = –30° to +85°C | TSSOP–16L |

**Simplified Application**




This device contains 164 active transistors.

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{S(max)}$ | 6.0 | Vdc |
| Junction Temperature | $T_{Jmax}$ | 150 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**NOTE:** ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_S$ | 2.7 to 5.5 | Vdc |
| Input Frequency | $f_{in}$ | 10 to 600 | MHz |
| Ambient Temperature Range | $T_A$ | –30 to +85 | °C |
| Input Signal Level at Local Input | $V_{in}$ | –10 | dBm |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_S$ = 3.0 V; No Input Signal)

| Characteristics | Conditions | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Total Drain Current 1 | Active Mode | $I_{CC1}$ | 4.5 | 5.5 | 7.5 | mA |
| Total Drain Current 2 | Disable Mode | $I_{CC2}$ | – | 0.1 | 10 | μA |

## AC ELECTRICAL CHARACTERISTICS

| Characteristics | Conditions | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **MIXER** ($T_A$ = 25°C; $V_S$ = 3.0; $f_{RF}$ = 240 MHz, $f_{LO}$ = 229.3 MHz) | | | | | | |
| Mixer Conversion Gain | 50 Ω Termination<br>Input Matched | – | 11<br>– | 14<br>21 | 17<br>– | dB |
| Noise Figure | Input Matched | NF | – | 14 | – | dB |
| Mixer Input Impedance | Single–Ended | Rp<br>Cp | –<br>– | 400<br>4.0 | –<br>– | Ω<br>pF |
| Mixer Output Impendance | – | – | – | 330 | – | Ω |
| 1.0 dB Gain Compression | @$Mix_{in}$ | Vicp | – | –16 | – | dBm |
| 3rd Order Input Intercept | 50 Ω Termination | IIP3 | – | –8.0 | – | dBm |
| **IF AMPLIFIER SECTION** ($T_A$ = 25°C; $V_S$ = 3.0 V; $f_{IF}$ = 10.7 MHz) | | | | | | |
| IF Gain | f = 10.7 MHz | – | 32 | 36 | 45 | dB |
| Input Impedance | – | – | – | 330 | – | Ω |
| Output Impedance | – | – | – | 330 | – | Ω |
| **LIMITING AMPLIFIER SECTION** ($T_A$ = 25°C; $V_S$ = 3.0 V; $f_{IF}$ = 10.7 MHz) | | | | | | |
| Limiter Gain | f = 10.7 MHz | – | – | 70 | – | dB |
| Input Impedance | – | – | – | 330 | – | Ω |
| Output Swing | – | – | 400 | 500 | 600 | mVpp |
| Output Rise Time | – | – | – | 10 | – | ns |
| Output Fall Time | – | – | – | 20 | – | ns |
| **RSSI SECTION** ($T_A$= 25°C; $V_S$ = 3.0 V; $f_{IF}$ = 10.7 MHz) | | | | | | |
| RSSI Slope | – | – | 10 | 14 | 18 | mV/dB |
| RSSI Output DC Voltage 1 | No Input Signal | – | 0.8 | 0.9 | 1.0 | V |
| RSSI Output DC Voltage 2 | $V_{IF}$ = –85 dBm | – | 0.82 | 0.95 | 1.02 | V |
| RSSI Output DC Voltage 3 | $V_{IF}$ = –80 dBm | – | 0.85 | 1.0 | 1.15 | V |
| RSSI Output DC Voltage 4 | $V_{IF}$ = –40 dBm | – | 1.4 | 1.5 | 1.6 | V |
| RSSI Output DC Voltage 5 | $V_{in}$ = 0 dBm | – | 1.95 | 2.1 | 2.25 | V |

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**Figure 1. Test Circuit**

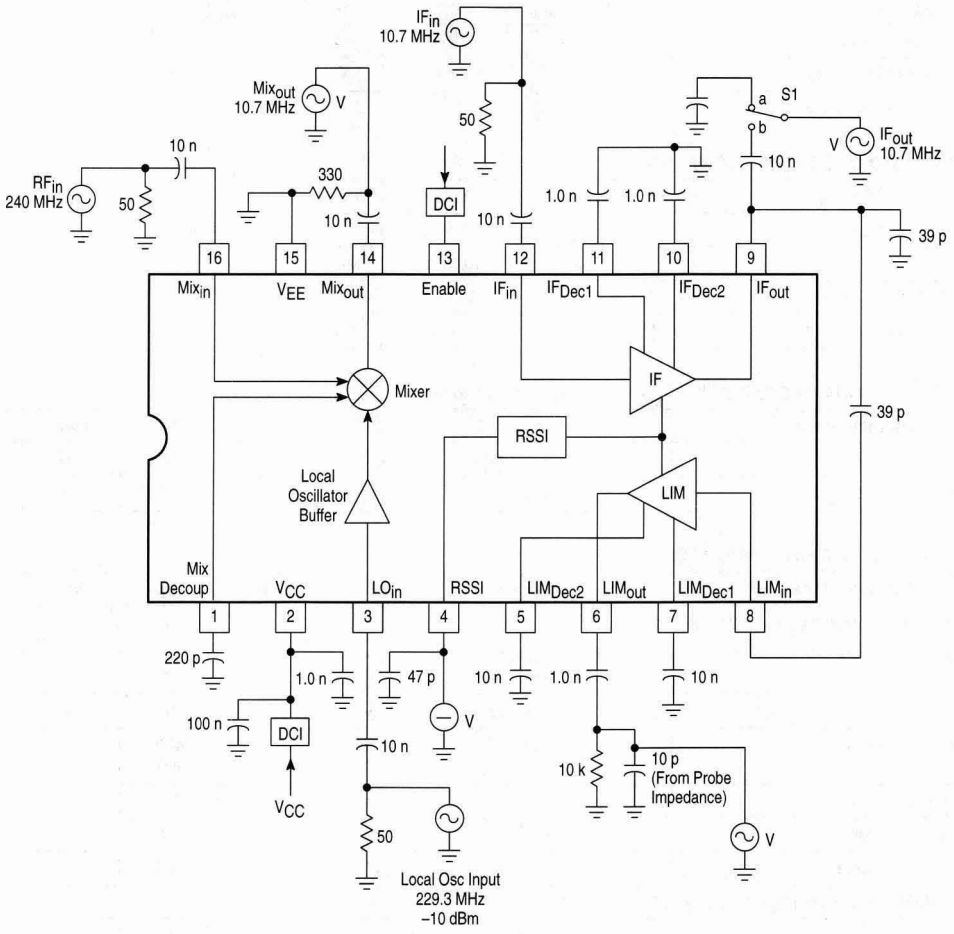


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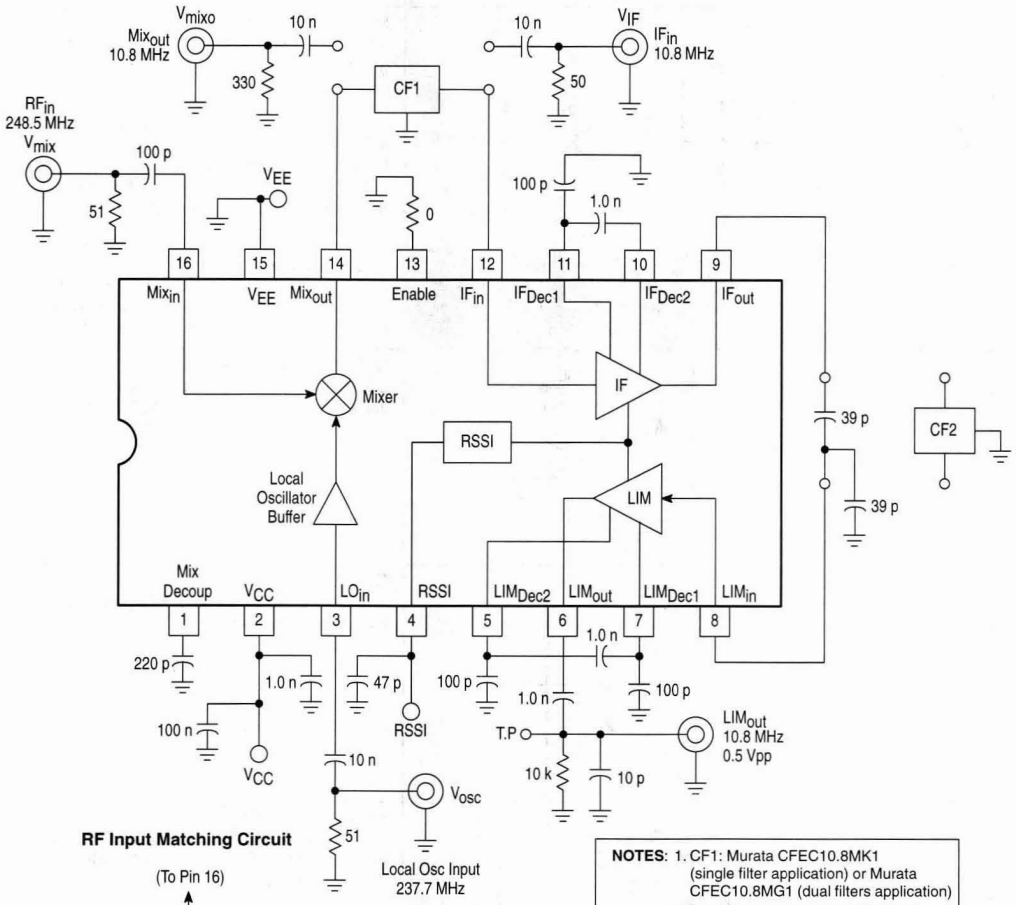
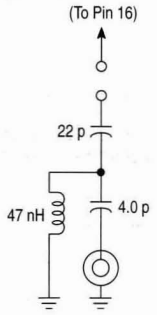
**Figure 2. Test Circuit for Evaluation**




**RF Input Matching Circuit**




**NOTES:** 1. CF1: Murata CFEC10.8MK1 (single filter application) or Murata CFEC10.8MG1 (dual filters application)
2. CF2: Murata CFEC10.8ME1 (dual filters application)

: BNC (unless otherwise specified)

: Banana Jack

**NOTE:** All resistors and capacitors are the chip components except coupling at CF2.

Text boards are for the TSSOP package and socket.

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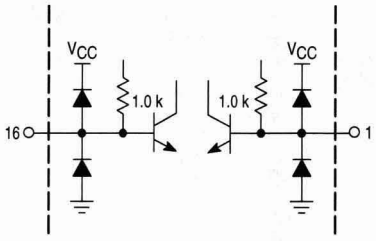
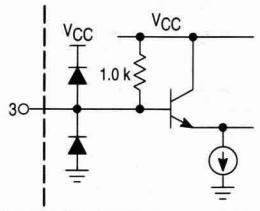
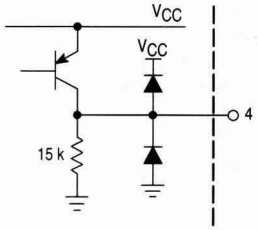
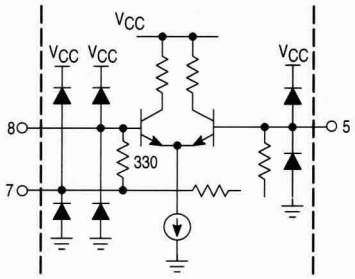
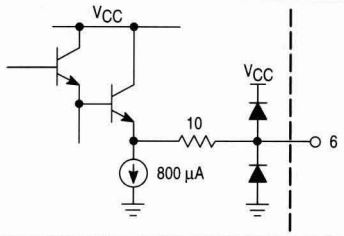
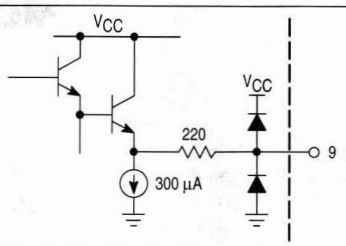
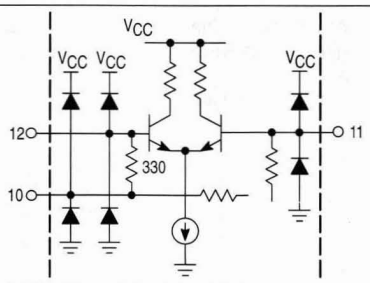
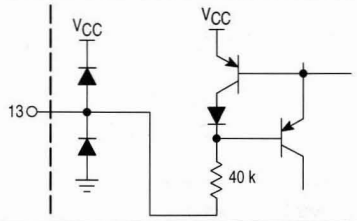
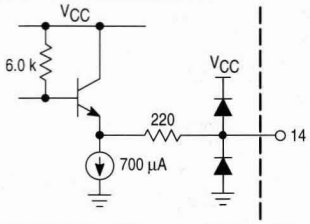
## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 1 | Mix Decoup |  | **Mixer Decoupling**<br>Mixer decoupling pin. 220 pF is decoupled to the RF ground. This pin also can be used for differential input with $Mix_{in}$. |
| 16 | $Mix_{in}$ | | **Mixer Input**<br>Input impedance is about 400 Ω at 240 MHz. Single–ended matching section at 240 MHz is referenced at application circuit. |
| 2 | $V_{CC}$ | | **Supply Voltage**<br>Supply voltage range range is from 2.7 Vdc to 5.5 Vdc. 1.0 nF of decoupling capacitor is placed directly at this pin to reduce the floor noise. |
| 3 | $LO_{in}$ |  | **Local Oscillator Input**<br>Connected to external local oscillator. Input impedance is about 900 Ω at 230 MHz. |
| 4 | RSSI |  | **RSSI**<br>The RSSI current creates a voltage drop across an internal 15 kΩ resistor. |
| 5<br>7 | $LIM_{Dec2}$<br>$LIM_{Dec1}$ |  | **Limiter Decoupling**<br>Limiter decoupling pins. Decoupling capacitors are connected to the RF ground, and one is placed between Dec1 and Dec2. |
| 8 | $LIM_{in}$ | | **Limiter Input**<br>The input impedance is 330 Ω; it matches the 330 input resistance of a 10.7/10.8 MHz ceramic filter. |
| 6 | $LIM_{out}$ |  | **Limiter Output**<br>The output level is about 0.5 Vpp. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 9 | $IF_{out}$ |  | **IF Output**<br>The output impedance is 330 Ω; it matches the 330 input resistance of a 10.7/10.8 MHz ceramic filter. |
| 10<br>11 | $IF_{Dec2}$<br>$IF_{Dec1}$ |  | **IF Decoupling**<br>IF decoupling pins. Decoupling capacitor is connected from Dec1 to the RF ground, and one is placed between Dec1 and Dec2. |
| 12 | $IF_{in}$ | | **IF Input**<br>The input impedance is 330 Ω; it matches the 330 input resistance of a 10.7/10.8 MHz ceramic filter. |
| 13 | Enable |  | **Enable**<br>The IC regulators are enabled by placing this pin at $V_{EE}$. |
| 14 | $Mix_{out}$ |  | **Mixer Output**<br>The mixer output impedance is 330 Ω; it matches the 330 input resistance of a 10.7/10.8 MHz ceramic filter. |
| 15 | $V_{EE}$ | | **Supply Ground** |

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MOTOROLA

# MC13173

# Infrared Integrated Transceiver IC

**INFRARED TRANSCEIVER**

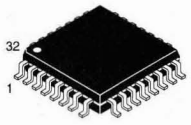
**SEMICONDUCTOR TECHNICAL DATA**

The MC13173 is a low power infrared integrated system (IRIS). It is a unique blend of a split IF wideband FM receiver and a specialized infrared LED transmitter. This device was designed to provide communications between portable computers via a half duplex infrared link at data rates up to 200 kbps.

The receiver includes a mixer, IF amplifier and limiter and data slicer. The IF amplifier is split to accommodate two low cost cascaded filters. The RSSI output is derived by summing the output of both IF sections.

The transmitter section includes a frequency synthesizer, FSK modulator, harmonic low pass filter and an IR LED driver.

- Transmitter Operates in Two Modes:
  - On/Off Pulsing for Remote Control
  - FSK Modulation at 1.4 MHz for Data Communications
- Over 70 dB of RSSI Range
- Split IF for Improved Filtering and Extended RSSI Range
- Digitally controlled Via a Six Line Interface Bus
- Individual Circuit Blocks Can Be Powered Down When Not In Use for Power Conservation




**FTB SUFFIX**
PLASTIC PACKAGE
CASE 873
(Thin QFP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13173FTB | $T_A = -40°$ to $+85°C$ | TQFP–32 |

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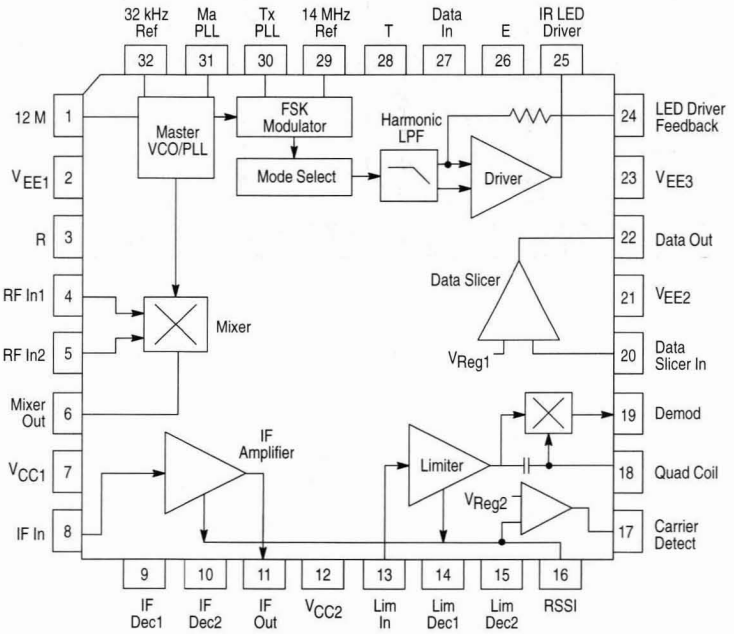
**Simplified Block Diagram**




This device contains 914 active transistors.

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC} - V_{EE}$ | 6.0 | Vdc |
| Junction Temperature | $T_J$ | 150 | °C |
| Storage Temperature | $T_{stg}$ | – 55 to +150 | °C |

**NOTE:** Devices should not be operated at or outside these values. The "Recommended Operating Conditions" table provides for actual device operation.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC} - V_{EE}$ | 2.7 to 5.5 | Vdc |
| Ambient Temperature Range | $T_A$ | – 40 to +85 | °C |

## DC ELECTRICAL CHARACTERISTICS ($T_A$ = +25°C, $V_{CC}$ = 3.3 Vdc, $f_{REF}$ = 32.768 kHz. Measured using test circuit in Figure 1, unless otherwise noted.)

| Characteristic | Control Pin Logic State T | R | E | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|---|
| Supply Current (See Table 2) | | | | 7, 12 | $I_{CC}$ | | | | |
| Receive Mode | 0 | 1 | 0 | | | – | 6.5 | 9.0 | mA |
| Communications Mode | 1 | 0 | 0 | | | – | 4.75 | 8.0 | |
| A/V Mode | 1 | 0 | 1 | | | – | 1.5 | – | |
| Standby Mode | 0 | 0 | 0 | | | – | <10 | – | nA |
| Master PLL Charge Current | | | | 31 | $I_{MA}$ | – | ±25 | – | µA |
| **DATA SLICER** | | | | | | | | | |
| Data Slicer Threshold Voltage | | | | 20 | $V_{TH1}$ | 0.85 | 1.1 | 1.4 | Vdc |
| Maximum Pull–Down Current | | | | 22 | $I_{DS}$ | 1.0 | 1.8 | – | mA |
| **CARRIER DETECT** | | | | | | | | | |
| Carrier Detect Threshold Voltage | | | | 16 | $V_{TH2}$ | 1.0 | 1.15 | 1.3 | Vdc |
| Maximum Pull–Down Current | | | | 17 | $I_{CD}$ | 1.1 | 3.0 | – | mA |
| **TRANSMITTER** | | | | | | | | | |
| Maximum Pull–Up Current | | | | 25 | $I_{OH}$ | 5.8 | 7.0 | – | mA |
| Maximum Pull–Down Current | | | | 25 | $I_{OL}$ | – | 150 | 700 | µA |
| DC Output Voltage | | | | 24 | $V_O$ | – | 200 | – | mV |
| Transmit PLL Charge Current | | | | 30 | $I_{TX}$ | – | ±25 | – | µA |

## AC ELECTRICAL CHARACTERISTICS ($T_A$ = +25°C, $V_{CC}$ = 3.3 Vdc, $f_{REF}$ = 32.768 kHz. Measured using test circuit in Figure 1, unless otherwise noted.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **TRANSMITTER** | | | | | | |
| Upper Sideband Frequency (Mark) | 24 | $f_{HI}$ | – | 1.427 | – | MHz |
| Lower Sideband Frequency (Space) | 24 | $f_{LO}$ | – | 1.317 | – | MHz |
| Upper and Lower Sideband Amplitude | 24 | $V_{SB}$ | 40 | 54 | 70 | mVrms |
| **RECEIVER** | | | | | | |
| Receiver Sensitivity – 12 dB SINAD | 4, 19 | $V_{SIN}$ | – | 5.0 | – | µV |
| **MIXER** | | | | | | |
| Mixer Conversion Gain | 4, 5, 6 | $AV_{(Mix)}$ | – | 23.5 | – | dB |
| Mixer Output Impedance | 6 | $Z_O$ | – | 330 | – | Ω |

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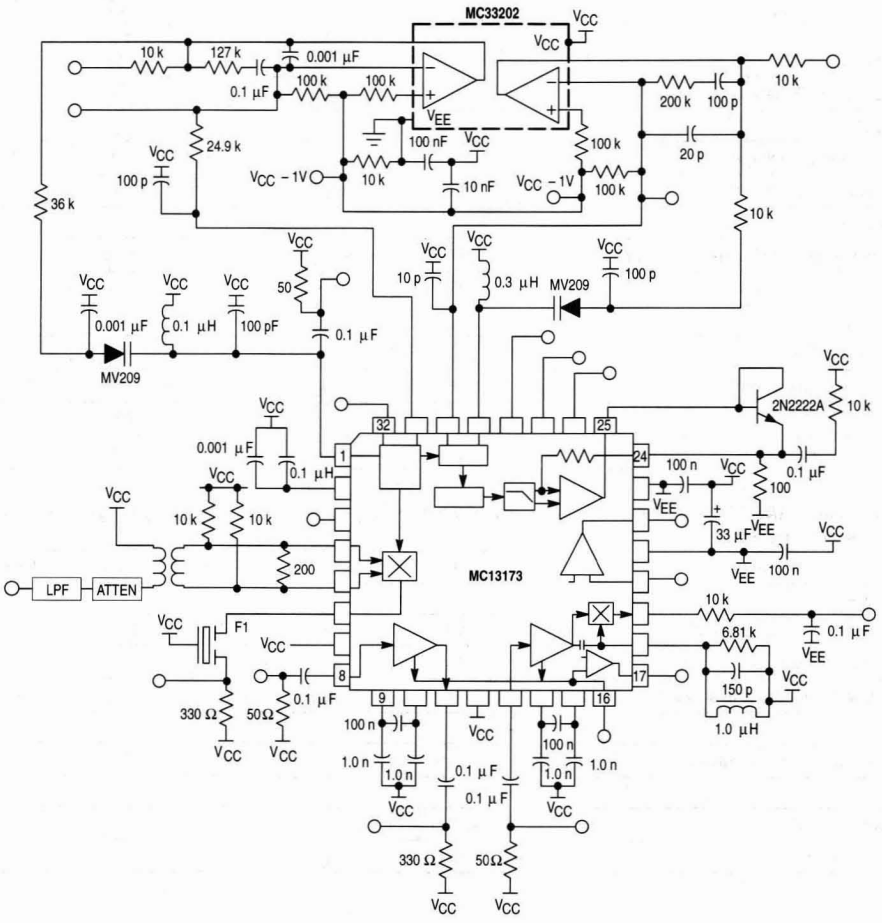
**AC ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = +25°C, $V_{CC}$ = 3.3 Vdc, $f_{REF}$ = 32.768 kHz. Measured using test circuit in Figure 1, unless otherwise noted.)

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **IF AMPLIFIER** | | | | | | |
| IF Amplifier Gain | 8, 11 | – | – | 54 | – | dB |
| IF Amplifier RSSI Slope | 16 | – | – | 275 | – | nA/dB |
| Input Impedance | 8 | $Z_{IN}$ | – | 330 | – | Ω |
| Output Impedance | 11 | $Z_O$ | – | 330 | – | Ω |
| RSSI Current Range | 16 | – | – | 20 | – | µA |
| RSSI Dynamic Range | 16 | – | – | 70 | – | dB |
| **LIMITING AMPLIFIER** | | | | | | |
| Input Impedance | 13 | $Z_{IN}$ | – | 330 | – | Ω |
| Limiter RSSI Slope | 16 | – | – | 360 | – | nA/dB |
| RSSI Current Range | 16 | – | – | 20 | – | µA |
| RSSI Dynamic Range | 16 | – | – | 58 | – | dB |

**Figure 1. Test Circuit**



## CIRCUIT DESCRIPTION

### General

The MC13173 infrared transceiver integrates a split IF wideband FM receiver and an IR LED transmitter into a single IC. The transmitter is comprised of an FSK modulator, harmonic low pass filter, and IR LED driver. The receiver consists of a mixer, IF amplifier and limiting IF, detector, and data slicer. It includes RSSI and carrier detect functions.

The transmitter is capable of two modes of operation. It was primarily designed for use in the Communications Mode, which enables point–to–point data links, such as the communication from keyboard to computer, or for the exchange of data between portable computers. In this mode it is capable of 200 kbps half duplex FSK operation.

The transmitter can also operate in an "A/V" Mode, which pulses the LED on and off with no carrier. (See Figure 11).

### Digital Interface Bus

The MC13173 is controlled via a six line 3.3 V digital interface bus. That includes three control pins, data in and out pins, and a carrier detect pin. Listed below is a brief description of each pin and its function.

**Table 1. Digital Interface Pin Descriptions**

| Pin | Pin Name | Symbol | I/O | Description |
|---|---|---|---|---|
| 28 | Transmit Enable | T | I | High – Transmitter is enabled<br>Low – Transmitter is disabled |
| 27 | Data In | DI | I | Data Input – 38.2 kbps<br>Communication Mode |
| 3 | Receive Enable | R | I | High – Receiver is enabled<br>Low – Receiver is disabled |
| 22 | Data Out | DO | O | Demodulated Output Signal |
| 17 | Carrier Detect | CD | O | High – Carrier is present<br>Low – Carrier is not present |
| 26 | Transmit Modulation Enable | E | I | High – Transmitter is in A/V Mode<br>Low – Transmitter is in Communications Mode |

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This transceiver was designed for use in battery powered, hand–held consumer products. To minimize power consumption, the digital interface enables individual system blocks to be powered down while not in use. The following diagram shows the mode of the IC and the power state of each circuit block for a given set of control levels.

**Table 2. Power State Table**

| Control Pins* | | | | Circuit Block Power States (See Figures 2 and 3) | | | | Supply Current (Typical) |
|---|---|---|---|---|---|---|---|---|
| T | R | E | Mode | Master VCO | FSK Modulator | Receiver | LED Driver | |
| 0 | 0 | 0 | OFF | Off | Off | Off | Off | 10 nA |
| 0 | 0 | 1 | OFF | Off | Off | Off | Off | 70 μA |
| 0 | 1 | X | Receive | On | Off | On | Off | 6.5 mA |
| 1 | 1 | 1 | Receive | On | Off | On | On | 7.5 mA |
| 1 | 1 | 0 | Transmit – Comm Mode | On | On | On | On | 9.0 mA |
| 1 | 0 | 0 | Transmit – Comm Mode | On | On | Off | On | 4.75 mA |
| 1 | 0 | 1 | Transmit – A/V Mode | Off | Off | Off | On | 1.5 mA |

* With Data In Pin Low

### Master VCO/PLL

The master VCO provides the reference frequency for the FSK modulator and the LO frequency for the receiver downconverter. With a 32.768 kHz input frequency to the master VCO on Pin 1, the LO frequency for the receiver will be at 12.075 MHz. The reference frequency for the FSK modulator will be at approximately 1.1 MHz. The master VCO and FSK modulator are not used when the transmitter is used in A/V mode, and both are powered down.

### Receiver Description

The single conversion receiver portion of the MC13173 is low power and wideband, and incorporates a split IF. This section includes a mixer, IF amplifier, limiting IF, quadrature detector and data slicer.

### Mixer

The mixer is a double balanced four quadrant multiplier. It can be driven either differentially or single–ended by connecting the unused input to the positive supply rail.

The buffered output is internally loaded for an output impedance of 330 Ω for use with a standard ceramic filter.

### IF Amplifier

The first IF amplifier section is composed of three differential stages with the second and third stages contributing to the RSSI. This section has internal DC feedback and external input decoupling for improved symmetry and stability. The total gain of the IF amplifier block is approximately 40 dB. The fixed internal input impedance is 330 Ω for use with a 10.7 MHz ceramic filter. The output of the IF amplifier is buffered and the impedance is 330 Ω.

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### Limiter

The limiter section is similar to the IF amplifier section, except that four stages are used with the last three contributing to the RSSI. This IF limiting amplifier section drives the quadrature detector internally.

### RSSI/Carrier Detect

The received signal strength indicator (RSSI) outputs a current proportional to the log of the received signal amplitude. The RSSI current output is derived by summing the currents from the IF and limiting amplifier stages. An external resistor sets the output voltage range.

The carrier detect threshold is set at approximately 1.2 Vdc. When the RSSI level exceeds that threshold, the carrier detect output will go high. A large resistor may be added externally between the comparator output and the positive input for hysteresis.

### Quadrature Detector

The demodulator is a conventional quadrature type with an external LC tank driven through an internal 5 pF capacitor. The output is buffered to give an output impedance of less than 1.0 kΩ at an average DC level of around 1.1 V.

### Data Slicer

The data slicer is designed to square up the data signal. It is self centering at about 1.1 V, and clips at about 0.75 V and 1.45 V. There is a short time constant for large peak–to–peak voltage swings or when there is a change in DC level at the detector output. The time constant is longer for small signals or for continuous bits of the same polarity which drift close to the threshold voltage.

### Transmission Description

The MC13173 uses a dual modulus PLL to frequency shift key (FSK) modulate the baseband digital input signal, producing the necessary logic high and low frequencies for transmission. The transmit frequency for a logic high is 1.427 MHz, and the frequency for a low is 1.317 MHz with a 32.768 kHz reference frequency.

### FSK Modulator

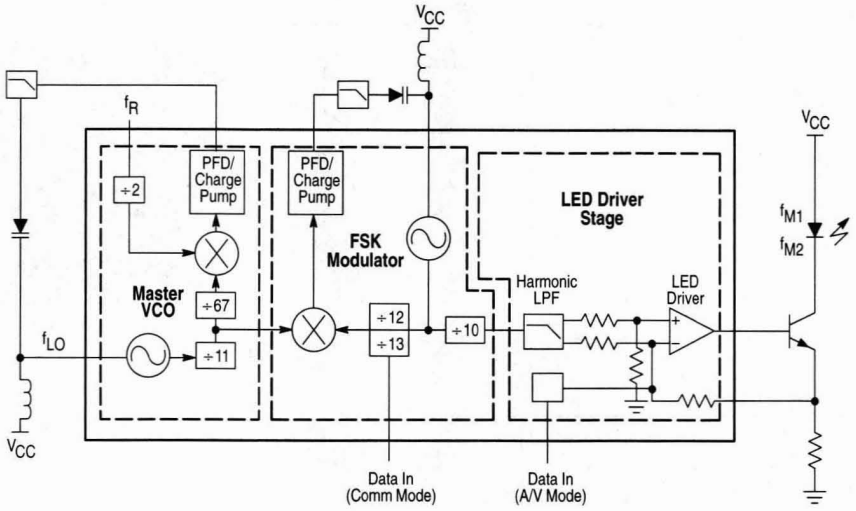
In the communications mode, the FSK modulator uses the reference frequency from the Master VCO to produce the two frequencies required for a logic high and a logic low. In the A/V mode, the FSK modulator is not used and is powered down.

### LED Driver Stage

A low pass filter following the FSK modulator removes the undesired harmonic frequencies from the square–wave output of the divider circuits in PLLs. The resulting sinusoidal waveforms are fed into a unity gain difference amplifier, which drives the base of an external transistor, modulating the IR LED.

In A/V mode, the data is input directly into the inverting input of the op amp, and the low pass filter is not used.

**Figure 2. Transmitter Block Diagram**




$f_R$ = 32.768 kHz

$f_{LO} = \frac{67 \times 11}{2} f_R$

Data High: $f_{M1} = \frac{13}{11 \times 10} f_{LO}$

Data Low: $f_{M2} = \frac{12}{11 \times 10} f_{LO}$

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**Figure 3. Receiver Block Diagram**

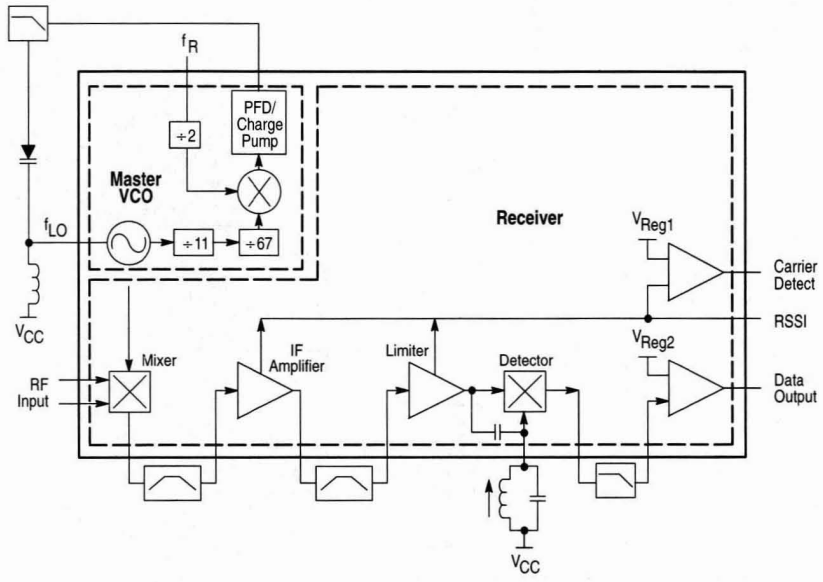


**Table 3. PIN FUNCTION DESCRIPTION** ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc, $f_{REF}$ = 32.768 kHz, $f_{MOD}$ = 32.768 kHz)

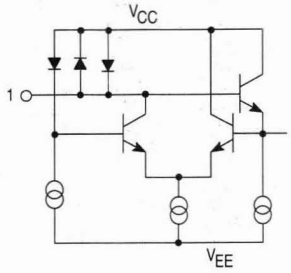
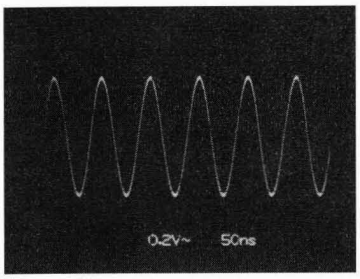
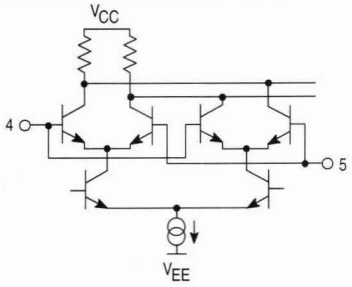
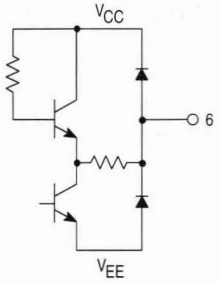
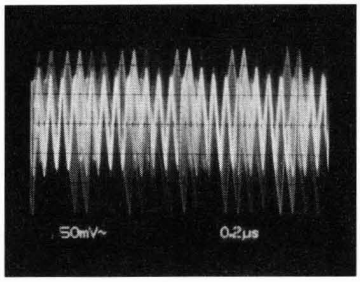
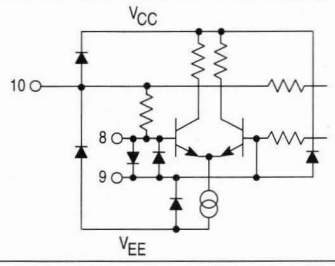
| Pin | Symbol | Description | Internal Equivalent Circuit | Waveform |
|---|---|---|---|---|
| 1 | 12 M | VCO for Master PLL.<br>(Measured using a low capacitance FET probe. Standard oscilloscope probes can pull oscillator off frequency. See Figure 14.) |  |  |
| 2, 21, 23 | $V_{EE}$ | DC ground. Should be connected to a continuous ground plane on the PCB. | | |
| 3 | R | Receive Enable Pin. See Tables 1 & 2. | | |
| 4, 5 | RF In1<br>RF In2 | RF Input to the mixer. 1.375 MHz average carrier frequency with ± 50 kHz deviation. |  | |
| 6 | Mixer Out | 10.7 MHz IF<br>$Z_O$ = 330 Ω<br>RF In = – 20 dBm<br>Modulation = 32.768 kHz |  |  |
| 7, 12 | $V_{CC}$ | Supply voltage and RF ground, should be decoupled to $V_{EE}$. | | |
| 8 | IF In | IF input impedance is 330 Ω.<br>RF In = – 20 dBm<br>Modulation = 32.768 kHz |  | |

**Table 3. PIN FUNCTION DESCRIPTION (continued)** ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc, $f_{REF}$ = 32.768 kHz, $f_{MOD}$ = 32.768 kHz)

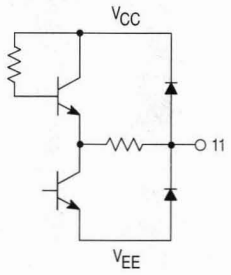
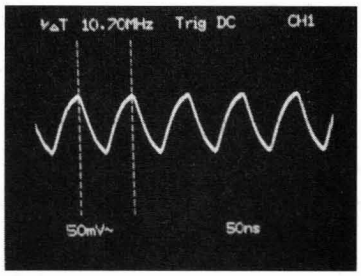
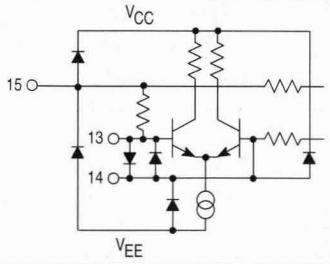
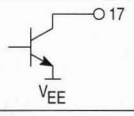
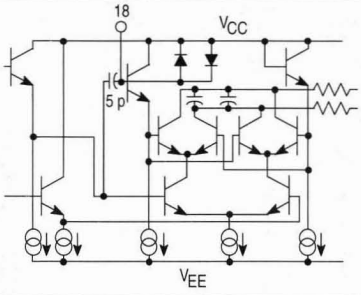
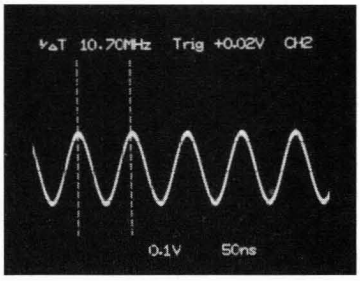
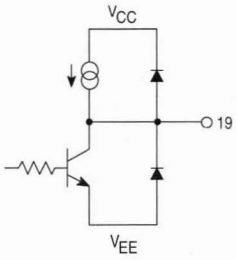
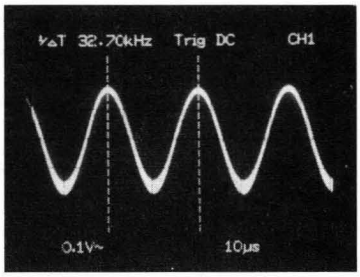
| Pin | Symbol | Description | Internal Equivalent Circuit | Waveform |
|---|---|---|---|---|
| 9, 10 | IF Dec | IF decoupling as shown in Figure 15. | See Circuit for Pin 8. | |
| 11 | IF Out | IF Output.<br>$Z_O$ = 330 Ω.<br>–20 dBm RF input level. Output is sinusoidal with lower drive levels. |  |  |
| 13 | Lim In | Limiter input.<br>$Z_{In}$ = 330 Ω. |  | |
| 14, 15 | Lim Dec | External limiter decoupling as shown in application circuit. | | |
| 16 | RSSI | Received Signal Strength Indicator Output. (See Figure 13) | | |
| 17 | Carrier Detect | Logic output of the carrier detect comparator. |  | |
| 18 | Quad Coil | Quadrature tuning circuit.<br>Modulated 10.7 MHz IF.<br>Measured with a low capacitance FET probe. |  |  |
| 19 | Demod | Demodulated signal output measured at the pin (before filtering).<br>Modulation = 32.768 kHz sine wave. |  |  |

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**Table 3. PIN FUNCTION DESCRIPTION (continued)** ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc, $f_{REF}$ = 32.768 kHz, $f_{MOD}$ = 32.768 kHz)

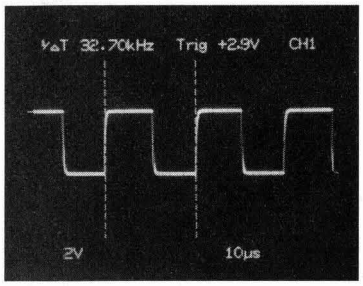
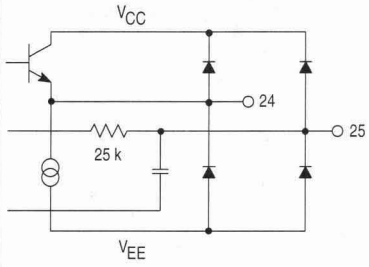
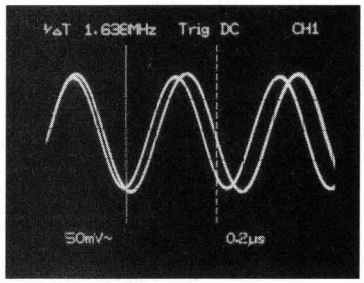
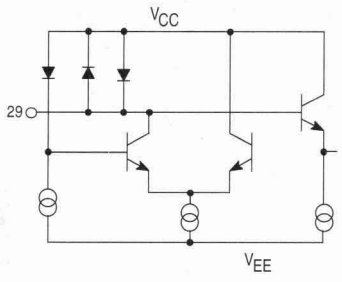
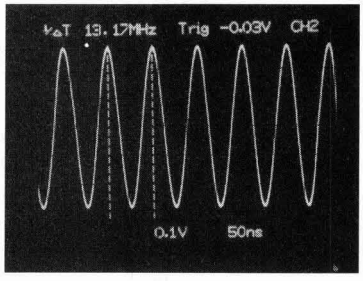
| Pin | Symbol | Description | Internal Equivalent Circuit | Waveform |
|---|---|---|---|---|
| 20 | Data Slicer In | Input from the receiver demodulated output. | | |
| 22 | Data Out | Output from the receiver data slicer.<br>Modulation = 32.768 kHz sine wave.<br>RF input driven by frequency generator. See also Figure 10. | |  |
| 24 | LED Driver Feed-back | Feedback for the LED driver op amp. | | |
| 25 | IR LED Driver | Output of the unity gain output buffer in Communications Mode. See Figure 11 for transmit output in A/V mode.<br>Modulation = 32.768 kHz square wave. |  |  |
| 26 | E | Transmit Modulation Enable. See Tables 1 & 2. | | |
| 27 | Data In | Modulation input for transmit data. | | |
| 28 | T | Transmit Enable pin. See Tables 1 & 2. | | |
| 29 | 14 MHz Ref | VCO for FSK Modulator phase locked loop.<br>(Measured using a low capacitance FET probe. Standard oscilloscope probes can pull oscillator off frequency. See Figure 14.)<br>No modulation (Data In low). |  |  |

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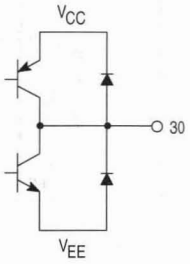
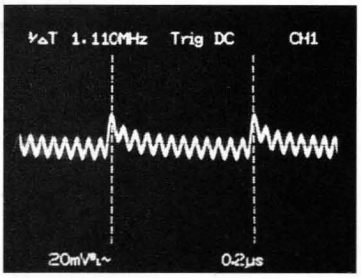
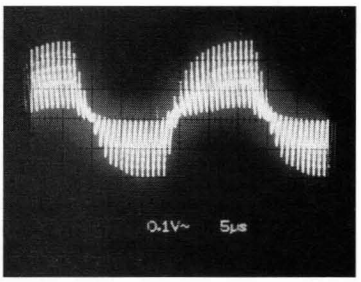
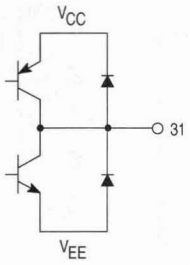
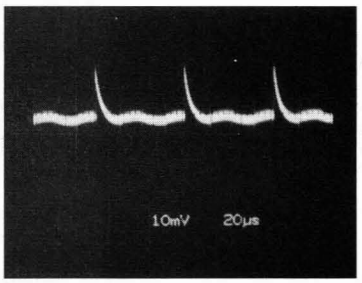
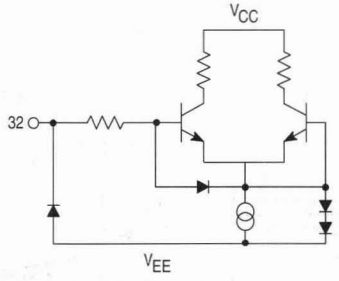
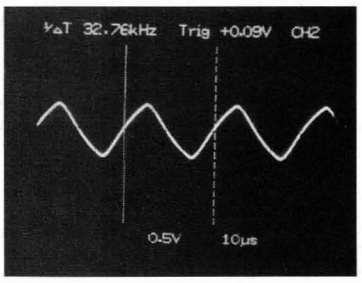
**Table 3. PIN FUNCTION DESCRIPTION (continued)** ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc, $f_{REF}$ = 32.768 kHz, $f_{MOD}$ = 32.768 kHz)

| Pin | Symbol | Description | Internal Equivalent Circuit | Waveform |
|---|---|---|---|---|
| 30 | Tx PLL | Phase detector output for the FSK Modulator.<br>(With loop closed and locked.)<br>No modulation (Data In low). |  |  |
| | | With 32.768 kHz square wave modulation.<br>Note: Probing the output of the phase detectors directly may disturb the loop. It is best to probe the output of the op amp when evaluating loop response. | |  |
| 31 | Ma PLL | Output of the phase detector charge pump for the Master PLL.<br>(With loop closed and locked.) |  |  |
| 32 | 32 kHz Ref | Input to 32.768 kHz reference. Filtered from TTL oscillator using application circuit in Figure 15.<br>Approximately 1.0 Vp–p triangle wave at 32.768 kHz. |  |  |

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**Typical Performance Over Temperature**
(Measured using test circuit in Figure 1)

**Figure 4. Normalized Mixer Gain versus Temperature**

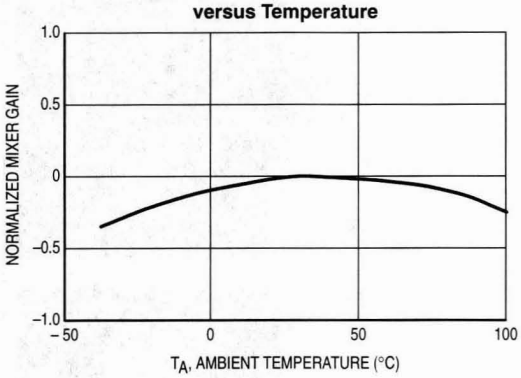



**Figure 5. Normalized IF Amp Gain versus Temperature**

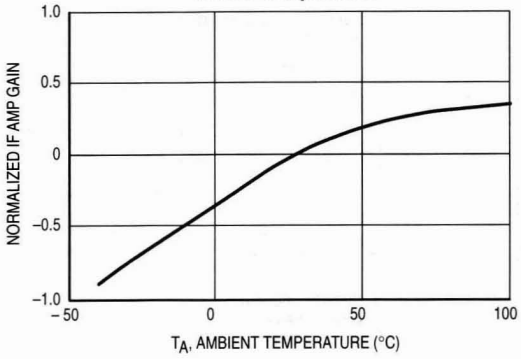



**Figure 6. Maximum Pull–Up Current versus Temperature (Pin 25)**

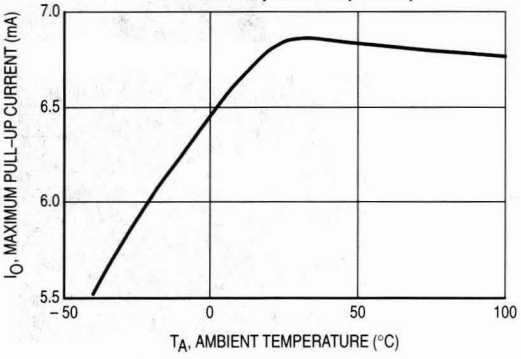



**Figure 7. Maximum Pull–Down Current versus Temperature (Pin 25)**

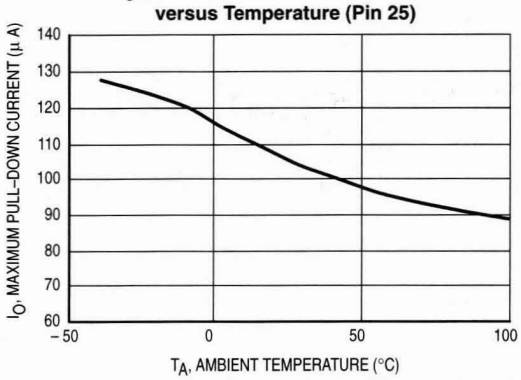



**Figure 8. Supply Current versus Temperature**

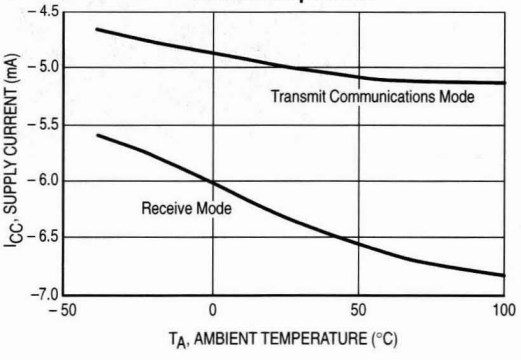
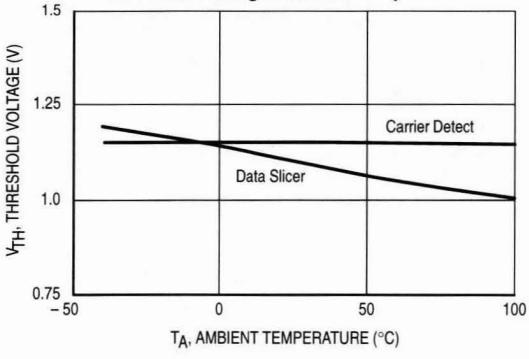



**Figure 9. Data Slicer and Carrier Detect Threshold Voltages versus Temperature**

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## APPLICATIONS INFORMATION

The MC13173 transceiver is specially designed to operate from a 32.768 kHz reference which is readily available in most computer applications. The frequency synthesizer on chip generates a receiver local oscillator frequency and the transmit mark and space frequencies from this fixed reference frequency, eliminating the need for additional crystals or manual tuning.

Large divide ratios are needed to generate these frequencies, however. For example, the receiver LO frequency is 368.5 times the 32.768 kHz reference frequency. This requires that the reference frequency be both accurate and stable. A two percent error in the reference frequency would pull the LO off frequency by over 240 kHz, putting the IF frequency out of the usable bandwidth of the filters and discriminator. For this reason, a 32.768 kHz oscillator circuit has been included on the demonstration board design. Although TTL crystal oscillators are available, this oscillator circuit uses an inexpensive tuning fork crystal and a hex inverter to generate a square wave reference frequency, which is then filtered and level adjusted to a 1.0 Vp–p triangle wave to drive pin 32. A TTL Clock Oscillator could also be used with the filter circuit as shown.

### Frequency Synthesizer

The recommended op amp for the external loop filter is the MC33202. For low voltage operation, ($V_{CC} \leq 3.3$ V) an op amp that is rail–to–rail on both the input and output is advisable to obtain the widest possible output voltage range without distortion. Sufficient distortion from the op amp such as phase reversal on the output caused by overdriving the inputs could prevent the loop from locking to the reference.

In debugging the loop filter, it is important to note that the FSK Modulator phase locked loop will not lock until the Master VCO is locked to the reference. If the application circuit in Figure 15 is used, both loops should lock without the need for any additional tweaking. Since the VCO has ±2.0 MHz of range using the MV209 varactor diode (see Figure 11), neither precision components nor tuning should be required. To ensure both loops are operating properly, first evaluate each VCO with the loop open and a voltage equal to $V_{CC}/2$ applied to the resistor in series with the varactor. Since there is a relatively small capacitance (<40 pF) in series with the LC tank circuit, the VCO pin is sensitive to any parasitic capacitance. Thus when using a standard oscilloscope probe having 10 to 20 pF capacitance it is difficult to measure the VCO frequency without shifting its frequency. A low capacitance FET probe used with a frequency counter will enable you to accurately measure the VCO frequency without altering it in the process.

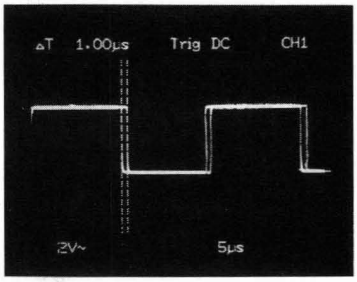
The free running frequency of the VCO should be approximately on frequency when the loop is open and the varactor is biased at mid–supply. The VCO for the Master PLL should run at 12.05 MHz. The free running frequency of the FSK Modulator should be at 13.72 MHz, midway between the two VCO frequencies needed to generate the transmit mark and space frequencies. The FSK Modulator loop is only active when the transmitter is enabled and the device is in the communications mode (see Tables 1 & 2). **If either the "T" pin is low or the "E" pin is high, the VCO will be off and you will see no oscillation on Pin 29.**

Once the loops are closed, the VCO frequencies should track the reference frequency within the hold–in range of the loop. Although the FSK Modulator loop is dependent on the Master VCO, the Master VCO is completely independent of the FSK Modulator. In fact, the FSK Modulator can be powered down (see Table 2) without affecting the Master VCO operation. In the application circuit in Figure 15 a single reference voltage for both op amps in the loop filters is provided by two diodes to $V_{CC}$. If the Master VCO is affected by the FSK Modulator loop, this generally indicates a problem with the common reference voltage to the op amp, and may mean the diodes are in backwards.

Once the loops are closed you should see a phase detector output such as is shown in the Pin Function Description in Table 3. If the VCO was on frequency when the loop was open, the phase detector outputs should swing around mid supply and not hit against either the positive or negative rail. Latching to $V_{CC}$ or $V_{EE}$ may indicate the loop filter circuitry is not implemented correctly.

Due to the digital design of the phase detectors, the transmitter can only transition between mark and space frequencies on a clock edge. On the receive side this may be seen as a double image on the detector output, with a discrete time delay which does not vary with the frequency of the data input (see Figure 10). This is a normal consequence of using a digital phase detector and should not be confused with jitter from the data slicer.

**Figure 10. Receive Data Output**
(Data Transmitted from Companion MC13173)



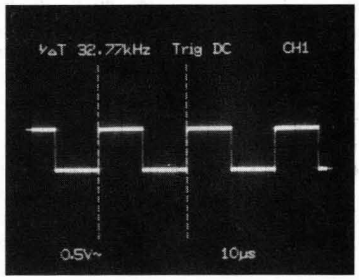

### Transmitter

The light emitting diode (LED) driver in the transmitter is capable of 6.0 to 10 mA of pull–up current. Selection of the external transistor and biasing resistor will depend on the LEDs used. Typical infrared LEDs require 50 to 100 mA of current and have a forward voltage of 1.5V. Sufficient current is needed to obtain the maximum power output without distorting the output by overdriving the LED. Key specifications include rise and fall time, wavelength, beam width (generally given in half–angle), maximum power output and efficiency. Choice of wavelengths is generally determined by cost and power efficiency, which may vary between vendors. The LEDs used in this application are at 880 nm and were chosen for best efficiency. However LEDs in general are very inefficient, converting only 1 or 2 percent of the electrical power into optical power. Multiple LEDs can be used to increase transceiver range.

Disabling the transmitter via the data bus turns off the output of the LED driver, removing the base current from the external transistor and thereby turning off the IR LED. Because of the high current drawn by the LED, this offers considerable power savings when the transmitter is not in use and can be easily controlled by a microcontroller with no additional circuitry.

In the "A/V" transmit mode, the data output is on/off keyed, with the LED on for a data high, and off for a data low. It is a baseband signal, with no carrier present (see Figure 11).

**Figure 11. LED Driver Output in A/V Mode**




**Receiver**

The receiver portion of the MC13173 is similar to the design of Motorola's MC13156 Wideband FM Receiver. Instead of using the mixer to downconvert from a higher RF frequency, this application is designed to upconvert the 1.372 MHz input to a 10.7 MHz IF. The wide deviation, relative to the RF input frequency, requires a low Q tuned circuit to recover this bandwidth:

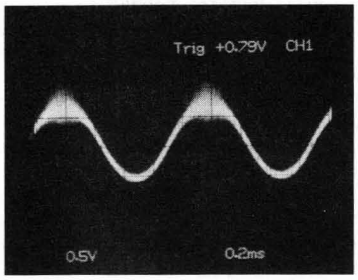
$$Q \approx \frac{f_c}{BW_{3\ dB}}, \text{ where } f_c = 1.372 \text{ MHz}$$

By Carson's Rule, the BW = 2(fdev + fmod). Since for mark/space frequencies of 1.317 MHz and 1.427 MHz the deviation is fixed at ±50 kHz, the bandwidth for a 50 kHz square wave (100 kbps) would be 200 kHz, and the tuned input requires a Q of less than 7. The low Q of the tank circuit reduces both the selectivity and the sensitivity of the receiver. For a Q of 7, the resistor required across the 56 µH inductor can be calculated:

$$R = QX_L = (7) \bullet (2\pi) \bullet (1.372\ E6) \bullet (56\ E{-}6)$$
$$R = 3.3\ k\Omega$$

The 10.7 MHz ceramic filters also need to be wide enough to pass the full frequency range which will include some harmonics. In the application circuit in Figure 15, Toko filters with a bandwidth of 330 kHz or 360 kHz are recommended to accommodate higher data rates. If the IF filters are too narrow, the recovered signal may have noise on the peaks (see Figure 12).

**Figure 12. Receive Data Output**




The RSSI has over 70 dB of dynamic range and 20 µA of current range. The RSSI output provides the input to the carrier detect comparator (see Figure 13) and a logarithmic output proportional to the input signal level. It can, therefore, be used to recover amplitude shift keyed (ASK) data.

The key specifications for the infrared detectors are response time, sensitivity, acceptance angle, and wavelength. Some vendors offer detectors in a black package with a built–in daylight filter. Although the transparent packages offer better sensitivity, the detectors with the daylight filter offer a much better signal to noise ratio. Response time (or maximum frequency) of the system is generally limited by the capability of the emitters rather than the detectors. For this application, a rise and fall time of 500 ns is sufficient.

**Design and Layout Considerations**

Although the frequencies in this design are low by RF standards, careful layout and good decoupling are still good practice. The high gain limiter and IF blocks should be decoupled as shown in the application circuit as near the IC as possible for best receiver performance. Also the TTL levels from the reference oscillator and the wide current swing applied to the IR LEDs can easily be picked up on $V_{CC}$, creating problems for the sensitive phase detector circuits and receiver RF inputs. Avoid long parallel traces and use plenty of decoupling to keep the supply rail clean.

## Typical Performance

(Measured using Application Circuit in Figure 15)

**Figure 13. RSSI Output Current versus RF Input Level**

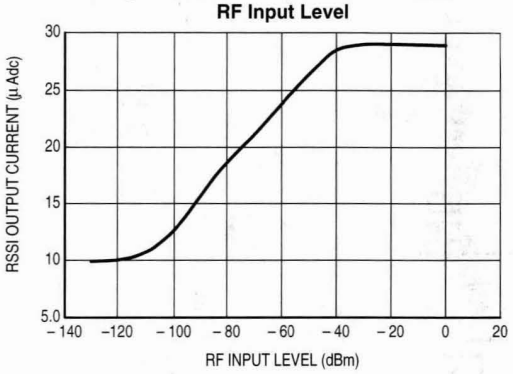



**Figure 14. VCO Frequency versus Varactor Voltage**

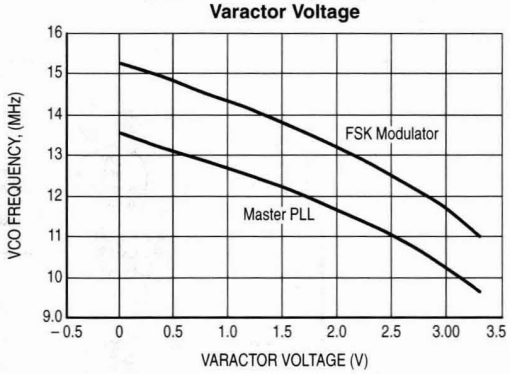
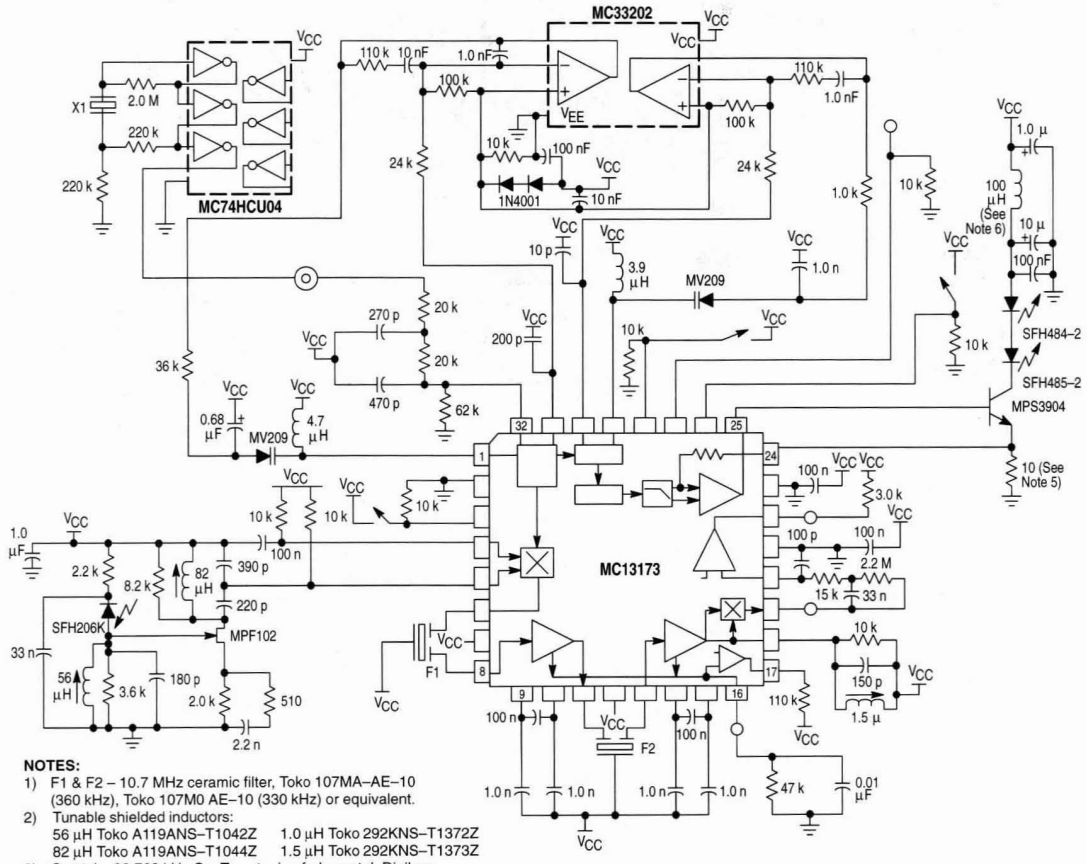



**Figure 15. Application Circuit**




**NOTES:**

1) F1 & F2 – 10.7 MHz ceramic filter, Toko 107MA–AE–10 (360 kHz), Toko 107M0 AE–10 (330 kHz) or equivalent.
2) Tunable shielded inductors:
   56 μH Toko A119ANS–T1042Z  1.0 μH Toko 292KNS–T1372Z
   82 μH Toko A119ANS–T1044Z  1.5 μH Toko 292KNS–T1373Z
3) Crystal – 32.768 kHz C – Type tuning fork crystal. Digikey part number SE3201 or equivalent.
4) LEDs and Detectors SFH484–2, SFH485–2 and SFH206K are made by Siemens.
5) Optimum bias resistor depends on the LEDs used.
6) May be fixed or tunable.

Figure 16. Component Placement

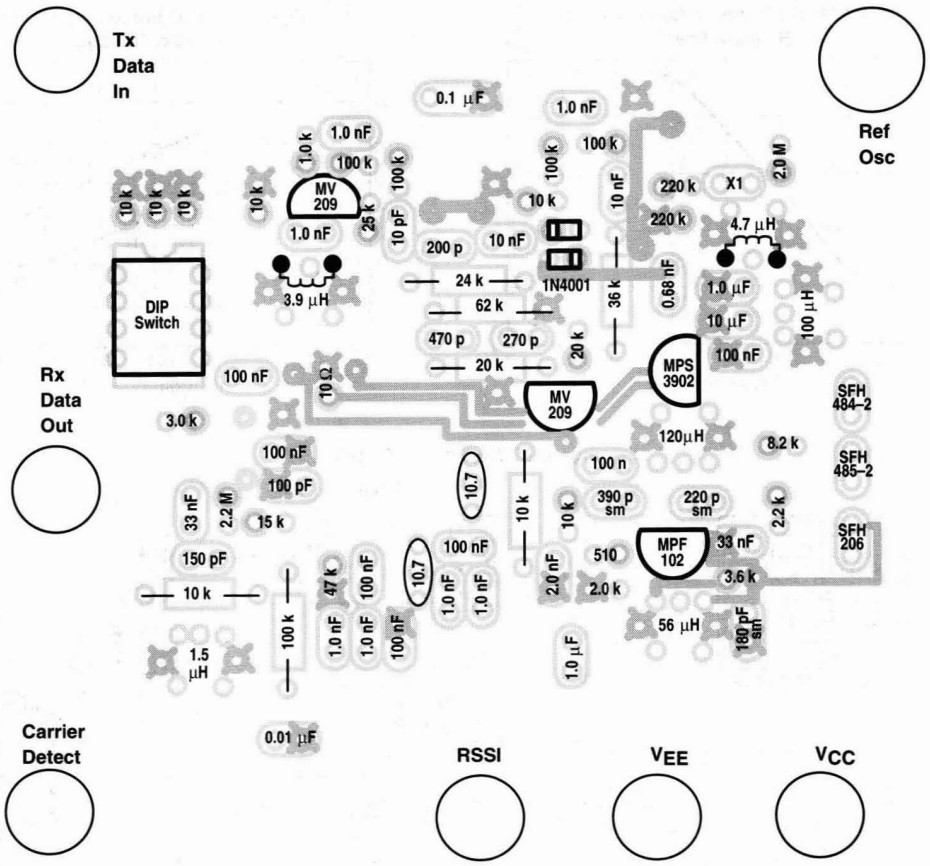



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Figure 17. Solder Side View

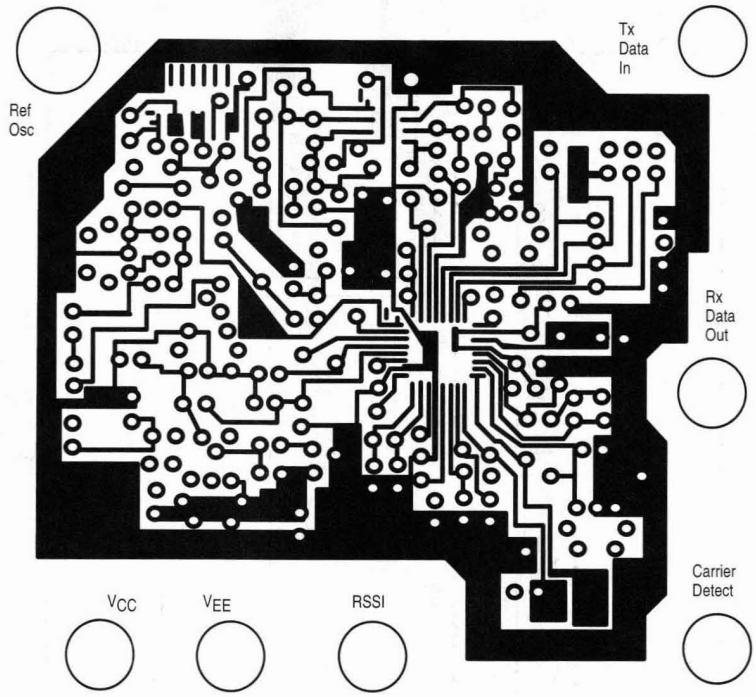



Figure 18. Component Side View

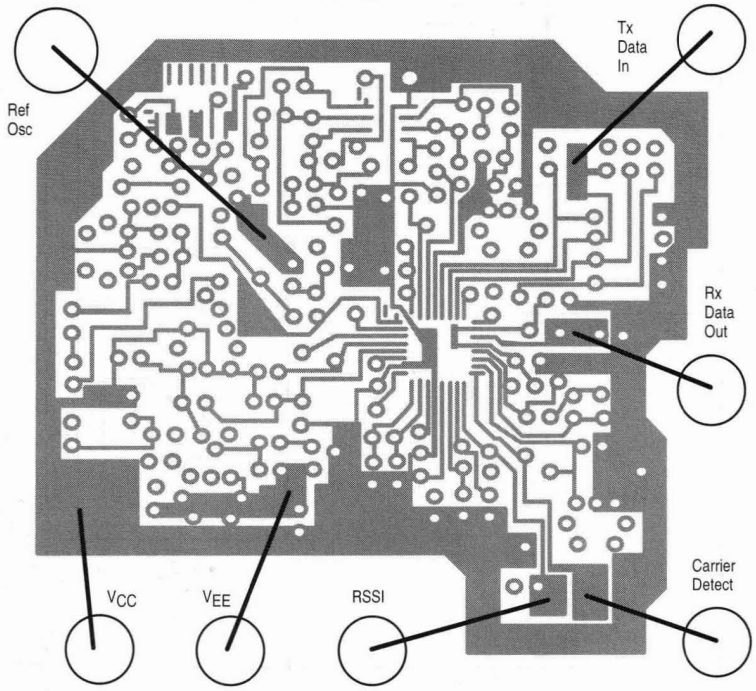
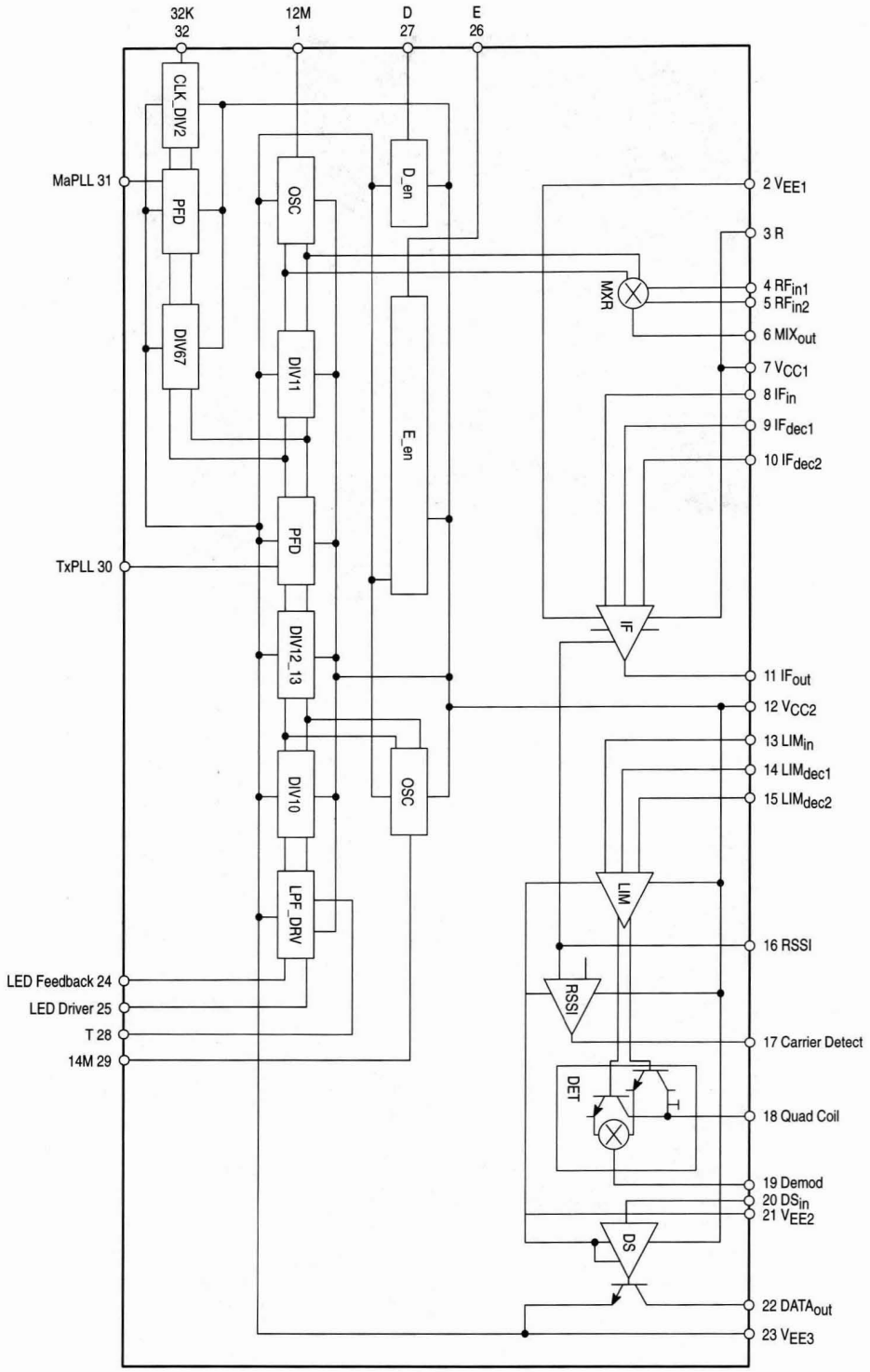


**Figure 19. Detailed Internal Block Diagram**



MOTOROLA

# UHF FM/AM Transmitter

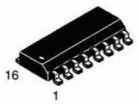
**MC13175**
**MC13176**

**UHF FM/AM TRANSMITTER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13175 and MC13176 are one chip FM/AM transmitter subsystems designed for AM/FM communication systems. They include a Colpitts crystal reference oscillator, UHF oscillator, ÷ 8 (MC13175) or ÷ 32 (MC13176) prescaler and phase detector forming a versatile PLL system. Targeted applications are in the 260 to 470 MHz band and 902 to 928 MHz band covered by FCC Title 47; Part 15. Other applications include local oscillator sources in UHF and 900 MHz receivers, UHF and 900 MHz video transmitters, RF Local Area Networks (LANs), and high frequency clock drivers. The MC13175/76 offer the following features:

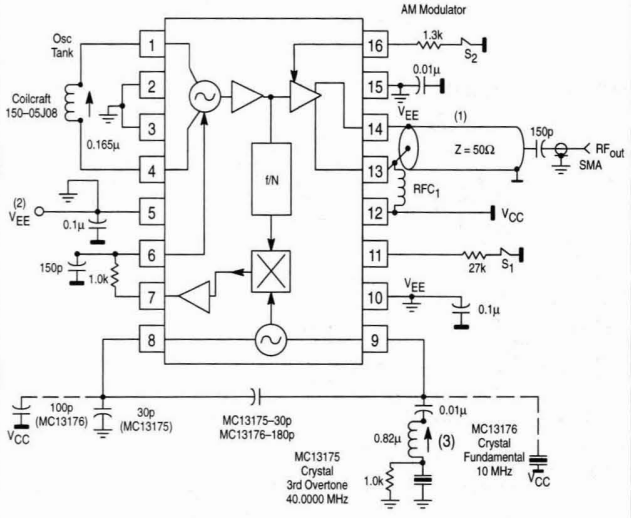
- UHF Current Controlled Oscillator
- Uses Easily Available 3rd Overtone or Fundamental Crystals for Reference
- Fewer External Parts Required
- Low Operating Supply Voltage (1.8 to 5.0 Vdc)
- Low Supply Drain Currents
- Power Output Adjustable (Up to +10 dBm)
- Differential Output for Loop Antenna or Balun Transformer Networks
- Power Down Feature
- ASK Modulated by Switching Output On and Off
- (MC13175) $f_O = 8 \times f_{ref}$; (MC13176) $f_O = 32 \times f_{ref}$




**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

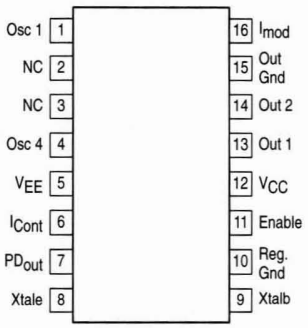
8

**Figure 1. Typical Application as 320 MHz AM Transmitter**




**NOTES:** 1. 50 Ω coaxial balun, 1/10 wavelength at 320 MHz equals 1.5 inches.
2. Pins 5, 10 & 15 are ground and connected to $V_{EE}$ which is the component/DC ground plane side of PCB. These pins must be decoupled to $V_{CC}$; decoupling capacitors should be placed as close as possible to the pins.
3. The crystal oscillator circuit may be adjusted for frequency with the variable inductor (MC13175); recommended source is Coilcraft "slot seven" 7mm tuneable inductor, Part #7M3–821. 1.0k resistor. Shunting the crystal prevents it from oscillating in the fundamental mode.

**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13175D | $T_A = -40°$ to $+85°C$ | SO–16 |
| MC13176D | | SO–16 |

**MAXIMUM RATINGS** ( $T_A$ = 25°C, unless otherwise noted.)

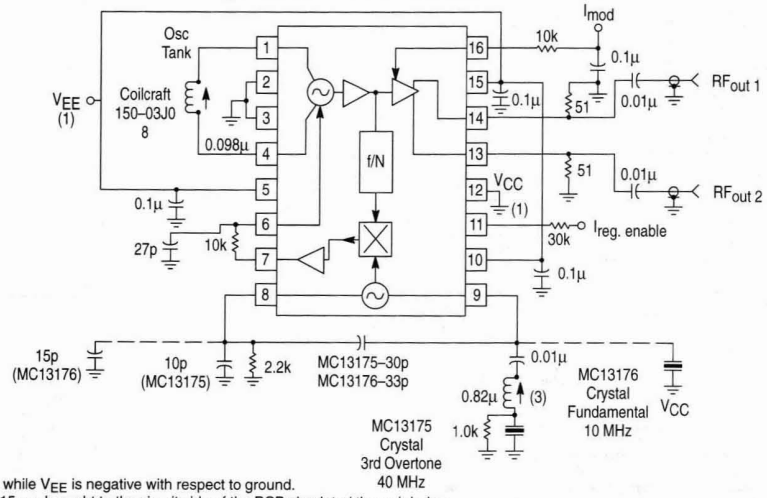
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 7.0 (max) | Vdc |
| Operating Supply Voltage Range | $V_{CC}$ | 1.8 to 5.0 | Vdc |
| Junction Temperature | $T_J$ | +150 | °C |
| Operating Ambient Temperature | $T_A$ | – 40 to + 85 | °C |
| Storage Temperature | $T_{stg}$ | – 65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** (Figure 2; $V_{EE}$ = – 3.0 Vdc, $T_A$ = 25°C, unless otherwise noted.)*

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Supply Current (Power down: $I_{11}$ & $I_{16}$ = 0) | – | $I_{EE1}$ | – 0.5 | – | – | µA |
| Supply Current (Enable [Pin 11] to $V_{CC}$ thru 30 k, $I_{16}$ = 0) | – | $I_{EE2}$ | –18 | –14 | – | mA |
| Total Supply Current (Transmit Mode) ($I_{mod}$ = 2.0 mA; $f_o$ = 320 MHz) | – | $I_{EE3}$ | – 39 | – 34 | – | mA |
| Differential Output Power ($f_o$ = 320 MHz; $V_{ref}$ [Pin 9] = 500 $mV_{p-p}$; $f_o$ = N x $f_{ref}$)<br>$I_{mod}$ = 2.0 mA (see Figure 7, 8)<br>$I_{mod}$ = 0 mA | 13 & 14 | $P_{out}$ | <br>2.0<br>– | <br>+ 4.7<br>– 45 | <br>–<br>– | dBm |
| Hold–in Range (± $\Delta f_{ref}$ x N)<br>MC13175 (see Figure 7)<br>MC13176 (see Figure 8) | 13 & 14 | ± $\Delta f_H$ | <br>3.5<br>4.0 | <br>6.5<br>8.0 | <br>–<br>– | MHz |
| Phase Detector Output Error Current<br>MC13175<br>MC13176 | 7 | $I_{error}$ | <br>20<br>22 | <br>25<br>27 | <br>–<br>– | µA |
| Oscillator Enable Time (see Figure 22b) | 11 & 8 | $t_{enable}$ | – | 4.0 | – | ms |
| Amplitude Modulation Bandwidth (see Figure 24) | 16 | $BW_{AM}$ | – | 25 | – | MHz |
| Spurious Outputs ($I_{mod}$ = 2.0 mA)<br>Spurious Outputs ($I_{mod}$ = 0 mA) | 13 & 14<br>13 & 14 | $P_{son}$<br>$P_{soff}$ | –<br>– | – 50<br>– 50 | –<br>– | dBc |
| Maximum Divider Input Frequency<br>Maximum Output Frequency | –<br>13 & 14 | $f_{div}$<br>$f_o$ | –<br>– | 950<br>950 | –<br>– | MHz |

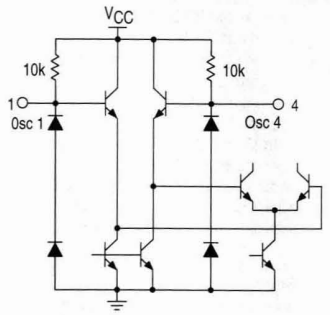
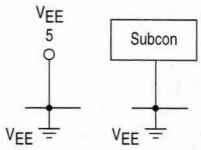
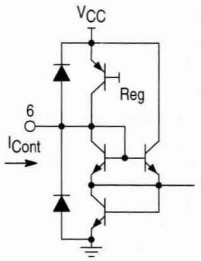
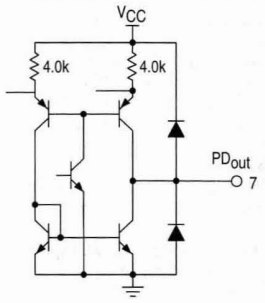
* For testing purposes, $V_{CC}$ is ground (see Figure 2).

**Figure 2. 320 MHz Test Circuit**




**NOTES:** 1. $V_{CC}$ is ground; while $V_{EE}$ is negative with respect to ground.
2. Pins 5, 10 and 15 are brought to the circuit side of the PCB via plated through holes. They are connected together with a trace on the PCB and each Pin is decoupled to $V_{CC}$ (ground).
3. Recommended source is Coilcraft "slot seven" inductor, part number 7M3–821.

## PIN FUNCTION DESCRIPTIONS

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 1 & 4 | Osc 1, Osc 4 |  | **CCO Inputs**<br>The oscillator is a current controlled type. An external oscillator coil is connected to Pins 1 and 4 which forms a parallel resonance LC tank circuit with the internal capacitance of the IC and with parasitic capacitance of the PC board. Three base–emitter capacitances in series configuration form the capacitance for the parallel tank. These are the base–emitters at Pins 1 and 4 and the base–emitter of the differential amplifier. The equivalent series capacitance in the differential amplifier is varied by the modulating current from the frequency control circuit (see Pin 6, internal circuit). A more thorough discussion is found in the Applications Information section. |
| 5 | $V_{EE}$ |  | **Supply Ground ($V_{EE}$)**<br>In the PCB layout, the ground pins (also applies to Pins 10 and 15) should be connected directly to chassis ground. Decoupling capacitors to $V_{CC}$ should be placed directly at the ground returns. |
| 6 | $I_{Cont}$ |  | **Frequency Control**<br>For $V_{CC}$ = 3.0 Vdc, the voltage at Pin 6 is approximately 1.55 Vdc. The oscillator is current controlled by the error current from the phase detector. This current is amplified to drive the current source in the oscillator section which controls the frequency of the oscillator. Figures 9 and 10 show the $\Delta f_{osc}$ versus $I_{Cont}$, Figure 5 shows the $\Delta f_{osc}$ versus $I_{Cont}$ at – 40°C, + 25°C and + 85°C for 320 MHz. The CCO may be FM modulated as shown in Figure 17, MC13176 320 MHz FM Transmitter. A detailed discussion is found in the Applications Information section. |
| 7 | $PD_{out}$ |  | **Phase Detector Output**<br>The phase detector provides ± 30 μA to keep the CCO locked at the desired carrier frequency. The output impedance of the phase detector is approximately 53 kΩ. Under closed loop conditions there is a DC voltage which is dependent upon the free running oscillator and the reference oscillator frequencies. The circuitry between Pins 7 and 6 should be selected for adequate loop filtering necessary to stabilize and filter the loop response. Low pass filtering between Pin 7 and 6 is needed so that the corner frequency is well below the sum of the divider and the reference oscillator frequencies, but high enough to allow for fast response to keep the loop locked. Refer to the Applications Information section regarding loop filtering and FM modulation. |

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## PIN FUNCTION DESCRIPTIONS

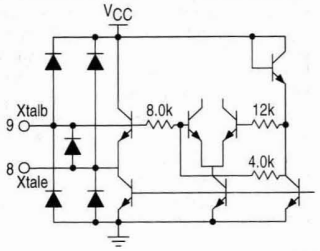
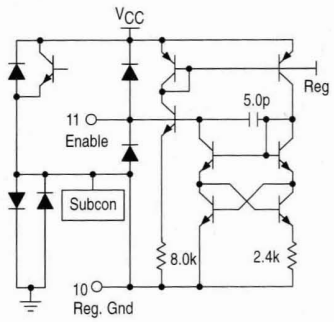
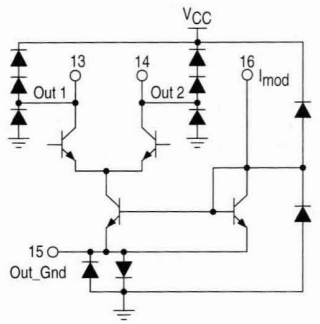
| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 8 | Xtale |  | **Crystal Oscillator Inputs**<br>The internal reference oscillator is configured as a common emitter Colpitts. It may be operated with either a fundamental or overtone crystal depending on the carrier frequency and the internal prescaler. Crystal oscillator circuits and specifications of crystals are discussed in detail in the applications section. With $V_{CC}$ = 3.0 Vdc, the voltage at Pin 8 is approximately 1.8 Vdc and at Pin 9 is approximately 2.3 Vdc. 500 to 1000 mVp–p should be present at Pin 9. The Colpitts is biased at 200 μA; additional drive may be acquired by increasing the bias to approximately 500 μA. Use 6.2 k from Pin 8 to ground. |
| 9 | Xtalb | | |
| 10 | Reg. Gnd |  | **Regulator Ground**<br>An additional ground pin is provided to enhance the stability of the system. Decoupling to the $V_{CC}$ (RF ground) is essential; it should be done at the ground return for Pin 10.<br><br>**Device Enable**<br>The potential at Pin 11 is approximately 1.25 Vdc. When Pin 11 is open, the transmitter is disabled in a power down mode and draws less than 1.0 μA $I_{CC}$ if the MOD at Pin 16 is also open (i.e., it has no current driving it). To enable the transmitter a current source of 10 μA to 90 μA is provided. Figures 3 and 4 show the relationship between $I_{CC}$, $V_{CC}$ and $I_{reg.\ enable}$. Note that $I_{CC}$ is flat at approximately 10 mA for $I_{reg.\ enable}$ = 5.0 to 100 μA ($I_{mod}$ = 0). |
| 11 | Enable | | |
| 12 | $V_{CC}$ | | **Supply Voltage ($V_{CC}$)**<br>The operating supply voltage range is from 1.8 Vdc to 5.0 Vdc. In the PCB layout, the $V_{CC}$ trace must be kept as wide as possible to minimize inductive reactances along the trace; it is best to have it completely fill around the surface mount components and traces on the circuit side of the PCB. |
| 13 & 14 | Out 1 and Out 2 |  | **Differential Output**<br>The output is configured differentially to easily drive a loop antenna. By using a transformer or balun, as shown in the application schematic, the device may then drive an unbalanced low impedance load. Figure 6 shows how much the Output Power and Free–Running Oscillator Frequency change with temperature at 3.0 Vdc; $I_{mod}$ = 2.0 mA.<br><br>**Output Ground**<br>This additional ground pin provides direct access for the output ground to the circuit board $V_{EE}$.<br><br>**AM Modulation/Power Output Level**<br>The DC voltage at this pin is 0.8 Vdc with the current source active. An external resistor is chosen to provide a source current of 1.0 to 3.0 mA, depending on the desired output power level at a given $V_{CC}$. Figure 23 shows the relationship of Power Output to Modulation Current, $I_{mod}$. At $V_{CC}$ = 3.0 Vdc, 3.5 dBm power output can be acquired with about 35 mA $I_{CC}$.<br>For FM modulation, Pin 16 is used to set the desired output power level as described above.<br>For AM modulation, the modulation signal must ride on a positive DC bias offset which sets a static (modulation off) modulation current. External circuitry for various schemes is further discussed in the Applications Information section. |
| 15 | Out_Gnd | | |
| 16 | $I_{mod}$ | | |

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**Figure 3. Supply Current versus Supply Voltage**

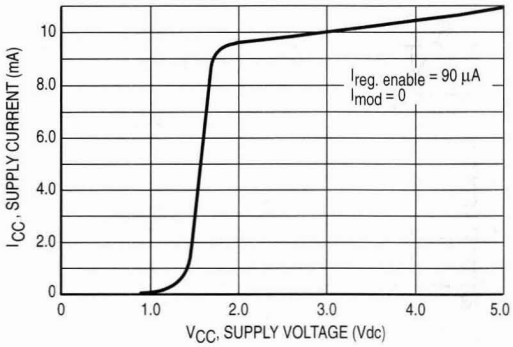



**Figure 4. Supply Current versus Regulator Enable Current**

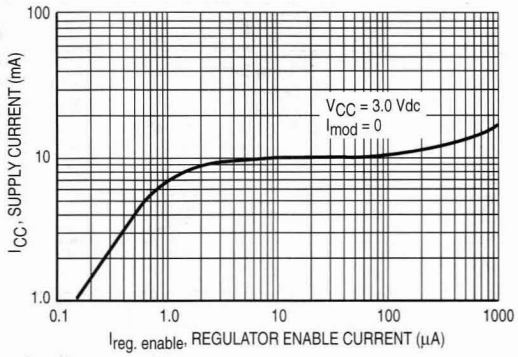



**Figure 5. Change Oscillator Frequency versus Oscillator Control Current**

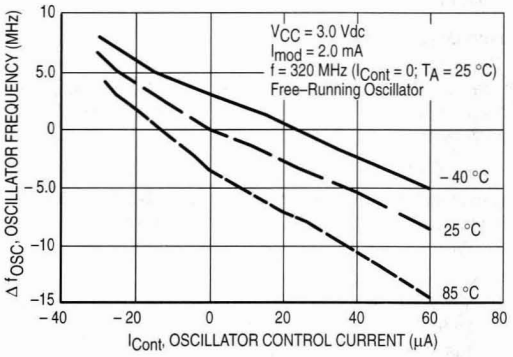

$V_{CC}$ = 3.0 Vdc
$I_{mod}$ = 2.0 mA
f = 320 MHz ($I_{Cont}$ = 0; $T_A$ = 25 °C)
Free–Running Oscillator
– 40 °C
25 °C
85 °C
Δ $f_{OSC}$, OSCILLATOR FREQUENCY (MHz)
$I_{Cont}$, OSCILLATOR CONTROL CURRENT (µA)

**Figure 6. Change in Oscillator Frequency and Output Power versus Ambient Temperature**

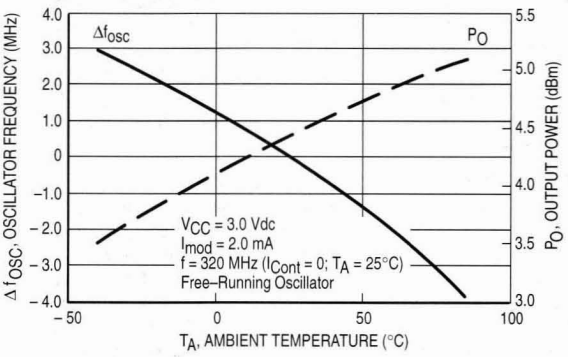



**Figure 7. MC13175 Reference Oscillator Frequency versus Phase Detector Current**

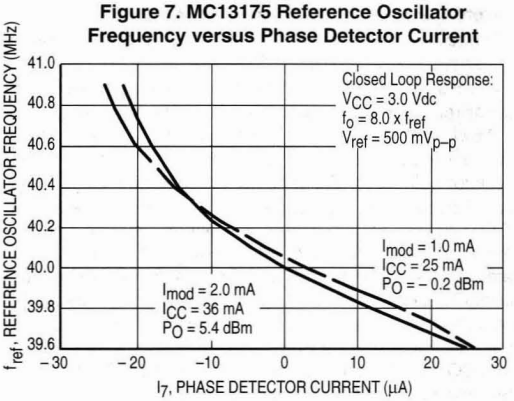
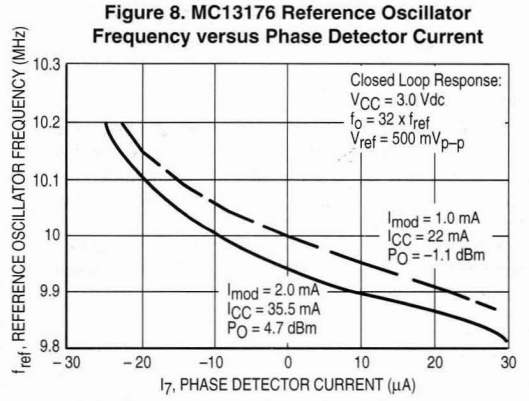

Closed Loop Response:
$V_{CC}$ = 3.0 Vdc
$f_o$ = 8.0 x $f_{ref}$
$V_{ref}$ = 500 $mV_{p-p}$
$I_{mod}$ = 1.0 mA
$I_{CC}$ = 25 mA
$P_O$ = – 0.2 dBm
$I_{mod}$ = 2.0 mA
$I_{CC}$ = 36 mA
$P_O$ = 5.4 dBm
$f_{ref}$, REFERENCE OSCILLATOR FREQUENCY (MHz)
$I_7$, PHASE DETECTOR CURRENT (µA)

**Figure 8. MC13176 Reference Oscillator Frequency versus Phase Detector Current**


Closed Loop Response:
$V_{CC}$ = 3.0 Vdc
$f_o$ = 32 x $f_{ref}$
$V_{ref}$ = 500 $mV_{p-p}$
$I_{mod}$ = 1.0 mA
$I_{CC}$ = 22 mA
$P_O$ = –1.1 dBm
$I_{mod}$ = 2.0 mA
$I_{CC}$ = 35.5 mA
$P_O$ = 4.7 dBm
$f_{ref}$, REFERENCE OSCILLATOR FREQUENCY (MHz)
$I_7$, PHASE DETECTOR CURRENT (µA)

8

**Figure 9. Change in Oscillator Frequency versus Oscillator Control Current**

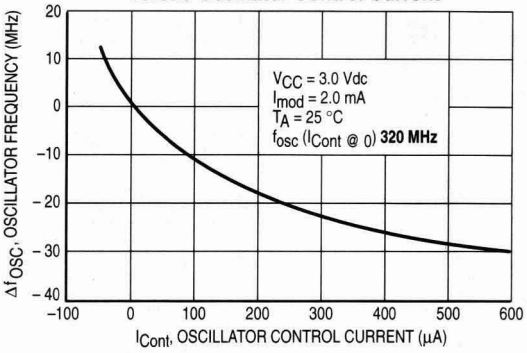
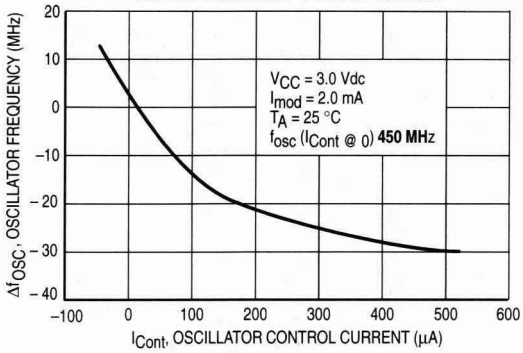



**Figure 10. Change in Oscillator Frequency versus Oscillator Control Current**




## APPLICATIONS INFORMATION

### Evaluation PC Board

The evaluation PCB, shown in Figures 26 and 27, is very versatile and is intended to be used across the entire useful frequency range of this device. The center section of the board provides an area for attaching all SMT components to the circuit side and radial leaded components to the component ground side of the PCB (see Figures 28 and 29). Additionally, the peripheral area surrounding the RF core provides pads to add supporting and interface circuitry as a particular application dictates. This evaluation board will be discussed and referenced in this section.

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### Current Controlled Oscillator (Pins 1 to 4)

It is critical to keep the interconnect leads from the CCO (Pins 1 and 4) to the external inductor symmetrical and equal in length. With a minimum inductor, the maximum free running frequency is greater than 1.0 GHz. Since this inductor will be small, it may be either a microstrip inductor, an air wound inductor or a tuneable RF coil. An air wound inductor may be tuned by spreading the windings, whereas tuneable RF coils are tuned by adjusting the position of an aluminum core in a threaded coilform. As the aluminum core coupling to the windings is increased, the inductance is decreased. The temperature coefficient using an aluminum core is better than a ferrite core. The UniCoil™ inductors made by Coilcraft may be obtained with aluminum cores (Part No. 51–129–169).

### Ground (Pins 5, 10 and 15)

**Ground Returns:** It is best to take the grounds to a backside ground plane via plated through holes or eyelets at the pins. The application PCB layout implements this technique. Note that the grounds are located at or less than 100 mils from the devices pins.

**Decoupling:** Decoupling each ground pin to $V_{CC}$ isolates each section of the device by reducing interaction between sections and by localizing circulating currents.

### Loop Characteristics (Pins 6 and 7)

Figure 11 is the component block diagram of the MC1317XD PLL system where the loop characteristics are described by the gain constants. Access to individual components of this PLL system is limited, inasmuch as the loop is only pinned out at the phase detector output and the frequency control input for the CCO. However, this allows for characterization of the gain constants of these loop components. The gain constants $K_p$, $K_o$ and $K_n$ are well defined in the MC13175 and MC13176.

### Phase Detector (Pin 7)

With the loop in lock, the difference frequency output of the phase detector is DC voltage that is a function of the phase difference. The sinusoidal type detector used in this IC has the following transfer characteristic:

$$I_e = A \sin \theta_e$$

The gain factor of the phase detector, $K_p$ (with the loop in lock) is specified as the ratio of DC output current, $I_e$ to phase error, $\theta_e$:

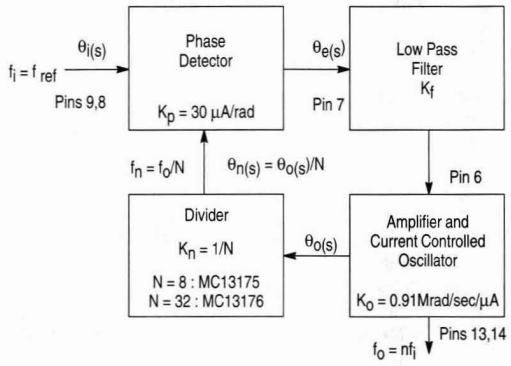
$$K_p = I_e/\theta_e \text{ (Amps/radians)}$$
$$K_p = A \sin \theta_e/\theta_e$$
$$\sin \theta_e \sim \theta_e \text{ for } \theta_e \leq 0.2 \text{ radians;}$$
$$\text{thus, } K_p = A \text{ (Amps/radians)}$$

Figures 7 and 8 show that the detector DC current is approximately 30 μA where the loop loses lock at $\theta_e = \pm \pi/2$ radians; therefore, $K_p$ is 30 μA/radians.

### Current Controlled Oscillator, CCO (Pin 6)

Figures 9 and 10 show the non–linear change in frequency of the oscillator over an extended range of control current for 320 and 450 MHz applications. $K_o$ ranges from approximately $6.3 \times 10^5$ rad/sec/μA or 100 kHz/μA (Figure 9) to $8.8 \times 10^5$ rad/sec/μA or 140 kHz/μA (Figure 10) over a relatively linear response of control current (0 to 100 μA). The oscillator gain factor depends on the operating range of the control current (i.e., the slope is not constant). Included in the CCO gain factor is the internal amplifier which can sink and source at least 30 μA of input current from the phase detector. The internal circuitry at Pin 6 limits the CCO control current to 50 μA of source capability while its sink capability exceeds 200 μA as shown in Figures 9 and 10. Further information to follow shows how to use the full capabilities of the CCO by addition of an external loop amplifier and filter (see Figure 15). This additional circuitry yields at $K_o$ = 0.145 MHz/μA or $9.1 \times 10^5$ rad/sec/μA.

**Figure 11. Block Diagram of MC1317XD PLL**



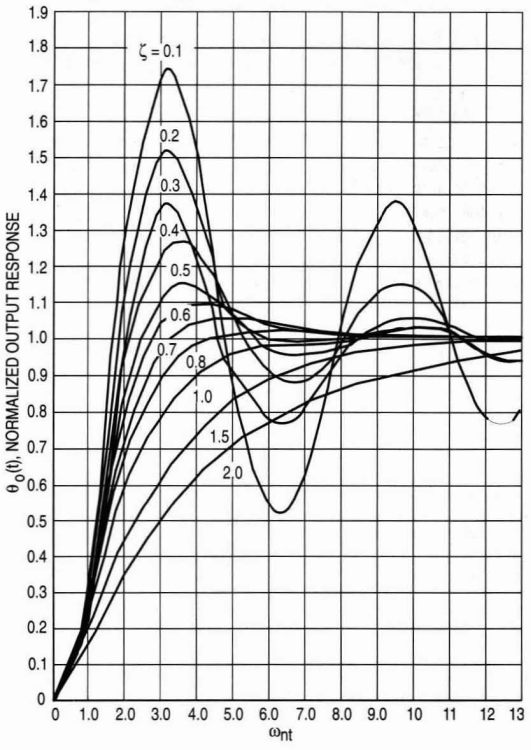

Where: $K_p$ = Phase detector gain constant in μA/rad; $K_p$ = 30 μA/rad
$K_f$ = Filter transfer function
$K_n$ = 1/N; N = 8 for the MC13175 and N = 32 for the MC13176
$K_o$ = CCO gain constant in rad/sec/μA
$K_o$ = 9.1 x $10^5$ rad/sec/μA

**Loop Filtering**

The fundamental loop characteristics, such as capture range, loop bandwidth, lock–up time and transient response are controlled externally by loop filtering.

The natural frequency ($\omega_n$) and damping factor ($\partial$) are important in the transient response to a step input of phase or frequency. For a given $\partial$ and lock time, $\omega_n$ can be determined from the plot shown in Figure 12.

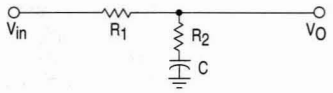
**Figure 12. Type 2 Second Order Response**




For $\partial$ = 0.707 and lock time = 1.0 ms;
then $\omega_n$ = 5.0/t = 5.0 krad/sec.

The loop filter may take the form of a simple low pass filter or a lag–lead filter which creates an additional pole at origin in the loop transfer function. This additional pole along with that of the CCO provides two pure integrators ($1/s^2$). In the lag–lead low pass network shown in Figure 13, the values of the low pass filtering parameters $R_1$, $R_2$ and C determine the loop constants $\omega_n$ and $\partial$. The equations $t_1 = R_1C$ and $t_2 = R_2C$ are related in the loop filter transfer functions $F(s) = 1 + t_2s/1 + (t_1 + t_2)s$.

**Figure 13. Lag–Lead Low Pass Filter**




The closed loop transfer function takes the form of a 2nd order low pass filter given by,

$$H(s) = K_vF(s)/s + K_vF(s)$$

From control theory, if the loop filter characteristic has F(0) = 1, the DC gain of the closed loop, $K_v$ is defined as,

$$K_v = K_pK_oK_n$$

and the transfer function has a natural frequency,

$$\omega_n = (K_v/t_1 + t_2)^{1/2}$$

and a damping factor,

$$\partial = (\omega_n/2)\ (t_2 + 1/K_v)$$

Rewriting the above equations and solving for the MC13176 with $\partial$ = 0.707 and $\omega_n$ = 5.0 k rad/sec:

$K_v = K_pK_oK_n = (30)\ (0.91 \times 10^6)\ (1/32) = 0.853 \times 10^6$
$t_1 + t_2 = K_v/\omega_n2 = 0.853 \times 10^6/(25 \times 106) = 34.1$ ms
$t_2 = 2\partial/\omega_n = (2)\ (0.707)/(5 \times 10^3) = 0.283$ ms
$t_1 = (K_v/\omega_n2) - t_2 = (34.1 - 0.283) = 33.8$ ms

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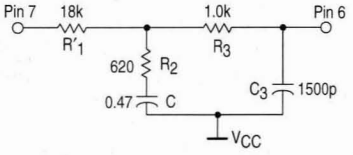
For C = 0.47 μ;
then, $R_1 = t_1/C = 33.8 \times 10^{-3}/0.47 \times 10^{-6} = 72$ k
dthus, $R_2 = t_2/C = 0.283 \times 10^{-3}/0.47 \times 10^{-6} = 0.60$ k
In the above example, the following standard value components are used,

C = 0.47 μ; $R_2$ = 620 and $R'_1$ = 72 k – 53 k ~ 18 k

($R'_1$ is defined as $R_1$ – 53 k, the output impedance of the phase detector.)

Since the output of the phase detector is high impedance (~50 k) and serves as a current source, and the input to the frequency control, Pin 6 is low impedance (impedance of the two diode to ground is approximately 500 Ω), it is imperative that the second order low pass filter design above be modified. In order to minimize loading of the $R_2C$ shunt network, a higher impedance must be established to Pin 6. A simple solution is achieved by adding a low pass network between the passive second order network and the input to Pin 6. This helps to minimize the loading effects on the second order low pass while further suppressing the sideband spurs of the crystal oscillator. A low pass filter with $R_3$ = 1.0 k and $C_2$ = 1500 p has a corner frequency ($f_c$) of 106 kHz; the reference sideband spurs are down greater than – 60 dBc.

**Figure 14. Modified Low Pass Loop Filter**




**Hold–In Range**

The hold–in range, also called the lock range, tracking range and synchronization range, is the ability of the CCO frequency, $f_O$ to track the input reference signal, $f_{ref} \bullet N$ as it gradually shifted away from the free running frequency, $f_f$. Assuming that the CCO is capable of sufficient frequency deviation and that the internal loop amplifier and filter are not overdriven, the CCO will track until the phase error, $\theta_e$ approaches $\pm\pi/2$ radians. Figures 5 through 8 are a direct measurement of the hold–in range (i.e. $\Delta f_{ref} \times N = \pm\Delta f_H \times 2\pi$). Since sin $\theta_e$ cannot exceed ±1.0, as $\theta_e$ approaches $\pm\pi/2$ the hold–in range is equal to the DC loop gain, $K_V \times N$.

$$\pm\Delta\omega_H = \pm K_V \times N$$

where, $K_V = K_p K_O K_n$.

In the above example,

$\pm\Delta\omega_H = \pm$ 27.3 Mrad/sec
$\pm\Delta f_H = \pm$ 4.35 MHz

**Extended Hold–in Range**

The hold–in range of about 3.4% could cause problems over temperature in cases where the free–running oscillator drifts more than 2 to 3% because of relatively high temperature coefficients of the ferrite tuned CCO inductor. This problem might worsen for lower frequency applications where the external tuning coil is large compared to internal capacitance at Pins 1 and 4. To improve hold–in range performance, it is apparent that the gain factors involved must be carefully considered.

$K_n$ = is either 1/8 in the MC13175 or 1/32 in the MC13176.
$K_p$ = is fixed internally and cannot be altered.
$K_o$ = Figures 9 and 10 suggest that there is capability of greater control range with more current swing. However, this swing must be symmetrical about the center of the dynamic response. The suggested zero current operating point for ±100 μA swing of the CCO is at about + 70 μA offset point.
Ka = External loop amplification will be necessary since the phase detector only supplies ± 30 μA.

In the design example in Figure 15, an external resistor ($R_5$) of 15 k to $V_{CC}$ (3.0 Vdc) provides approximately 100 μA of current boost to supplement the existing 50 μA internal source current. $R_4$ (1.0 k) is selected for approximately 0.1 Vdc across it with 100 μA. $R_1$, $R_2$ and $R_3$ are selected to set the potential at Pin 7 and the base of 2N4402 at approximately 0.9 Vdc and the emitter at 1.55 Vdc when error current to Pin 6 is approximately zero μA. $C_1$ is chosen to reduce the level of the crystal sidebands.

**Figure 15. External Loop Amplifier**

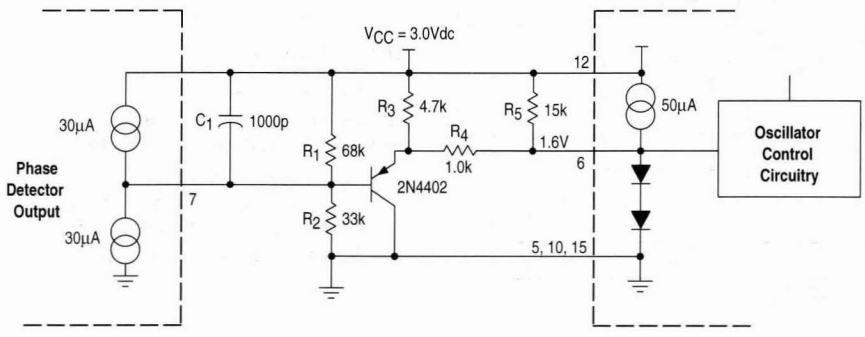
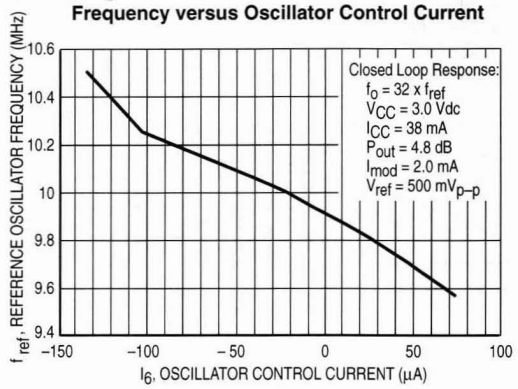


Figure 16 shows the improved hold–in range of the loop. The $\Delta f_{ref}$ is moved 950 kHz with over 200 μA swing of control current for an improved hold–in range of ±15.2 MHz or ± 95.46 Mrad/sec.

**Figure 16. MC13176 Reference Oscillator Frequency versus Oscillator Control Current**




### Lock–in Range/Capture Range

If a signal is applied to the loop not equal to free running frequency, $f_f$, then the loop will capture or lock–in the signal by making $f_s = f_o$ (i.e. if the initial frequency difference is not too great). The lock–in range can be expressed as $\Delta\omega_L \sim \pm 2\partial\omega_n$

### FM Modulation

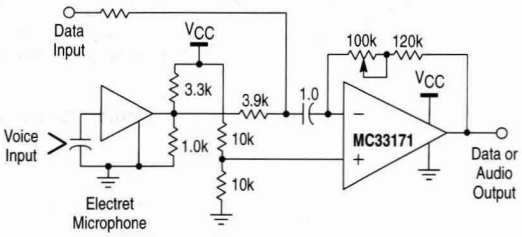
Noise external to the loop (phase detector input) is minimized by narrowing the bandwidth. This noise is minimal in a PLL system since the reference frequency is usually derived from a crystal oscillator. FM can be achieved by applying a modulation current superimposed on the control current of the CCO. The loop bandwidth must be narrow enough to prevent the loop from responding to the modulation frequency components, thus, allowing the CCO to deviate in frequency. The loop bandwidth is related to the natural frequency $\omega_n$. In the lag–lead design example where the natural frequency, $\omega_n$ = 5.0 krad/sec and a damping factor, $\partial$ = 0.707, the loop bandwidth = 1.64 kHz. Characterization data of the closed loop responses for both the MC13175 and MC13176 at 320 MHz (Figures 7 and 8, respectively) show satisfactory performance using only a simple low–pass loop filter network. The loop filter response is strongly influenced by the high output impedance of the push–pull current output of the phase detector.

$f_c$ = 0.159/RC;
For R = 1.0 k + $R_7$ ($R_7$ = 53 k) and C = 390 pF
$f_c$ = 7.55 kHz or $\omega_c$ = 47 krad/sec

The application example in Figure 17a of a 320 MHz FM transmitter demonstrates the FM capabilities of the IC. A high value series resistor (100 k) to Pin 6 sets up the current source to drive the modulation section of the chip. Its value is dependent on the peak to peak level of the encoding data and the maximum desired frequency deviation. The data input is AC coupled with a large coupling capacitor which is selected for the modulating frequency. The component placements on the circuit side and ground side of the PC board are shown in Figures 28 and 29, respectively. Figure 18a illustrates the input data of a 10 kHz modulating signal at 1.6 Vp–p. Figures 18b and 18c depict the deviation and resulting modulation spectrum showing the carrier null at – 40 dBc. Figure 18d shows the unmodulated carrier power output at 3.5 dBm for $V_{CC}$ = 3.0 Vdc.

For voice applications using a dynamic or an electret microphone, an op amp is used to amplify the microphone's low level output. The microphone amplifier circuit is shown in Figure 19. Figure 17b shows an application example for NBFM audio or direct FSK in which the reference crystal oscillator is modulated.

**Figure 19. Microphone Amplifier**




### Local Oscillator Application

To reduce internal loop noise, a relatively wide loop bandwidth is needed so that the loop tracks out or cancels the noise. This is emphasized to reduce inherent CCO and divider noise or noise produced by mechanical shock and environmental vibrations. In a local oscillator application the CCO and divider noise should be reduced by proper selection of the natural frequency of the loop. Additional low pass filtering of the output will likely be necessary to reduce the crystal sideband spurs to a minimal level.

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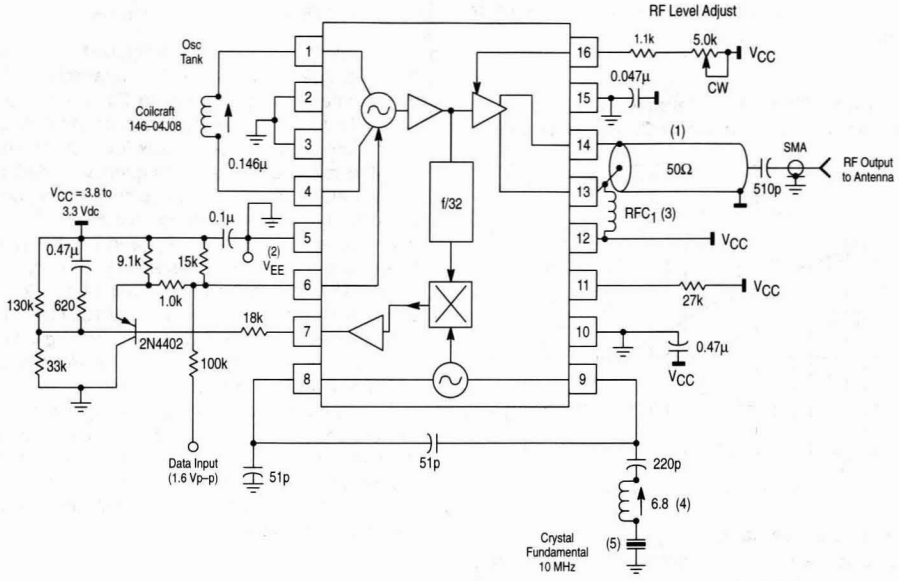
**Figure 17a. 320 MHz MC13176D FM Transmitter**




**NOTES:** 1. 50 Ω coaxial balun, 2 inches long.
2. Pins 5, 10 and 15 are grounds and connnected to $V_{EE}$ which is the component's side ground plane. These pins must be decoupled to $V_{CC}$; decoupling capacitors should be placed as close as possible to the pins.
3. $RFC_1$ is 180 nH Coilcraft surface mount inductor or 190 nH Coilcraft 146–05J08.
4. Recommended source is a Coilcraft "slot seven" 7.0 mm tuneable inductor, part #7M3–682.
5. The crystal is a parallel resonant, fundamental mode calibrated with 32 pF load capacitance.

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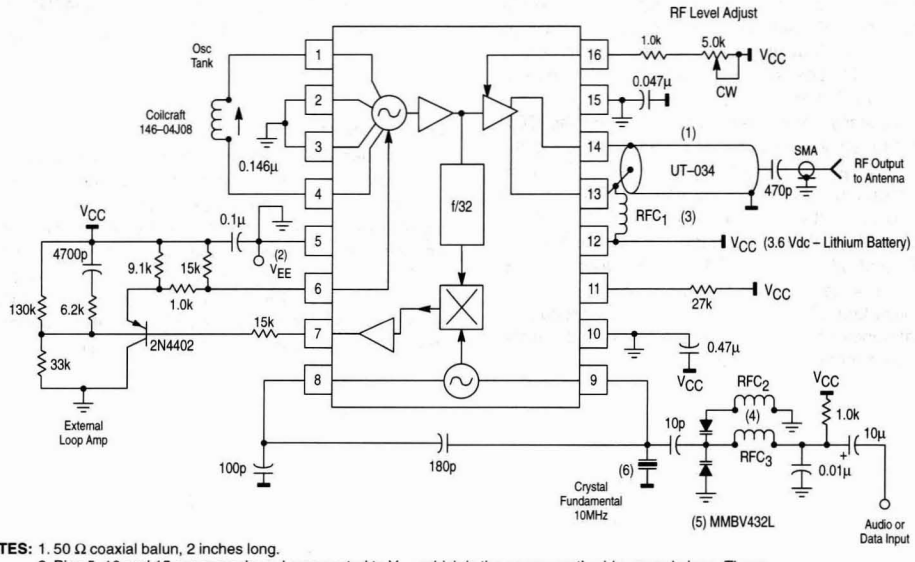
**Figure 17b. 320 MHz NBFM Transmitter**




**NOTES:** 1. 50 Ω coaxial balun, 2 inches long.
2. Pins 5, 10 and 15 are grounds and connnected to $V_{EE}$ which is the component's side ground plane. These pins must be decoupled to $V_{CC}$; decoupling capacitors should be placed as close as possible to the pins.
3. $RFC_1$ is 180 nH Coilcraft surface mount inductor.
4. $RFC_2$ and $RFC_3$ are high impedance crystal frequency of 10 MHz; 8.2 µH molded inductor gives XL > 1000 Ω.
5. A single varactor like the MV2105 may be used whereby $RFC_2$ is not needed.
6. The crystal is a parallel resonant, fundamental mode calibrated with 32 pF load capacitance.

Figure 18a. Input Data Waveform

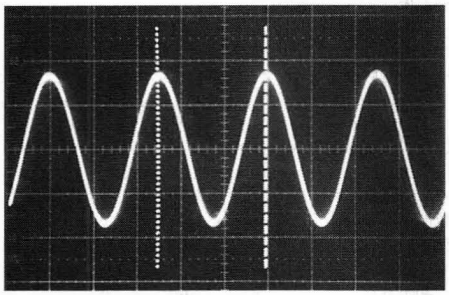


Figure 18b. Frequency Deviation

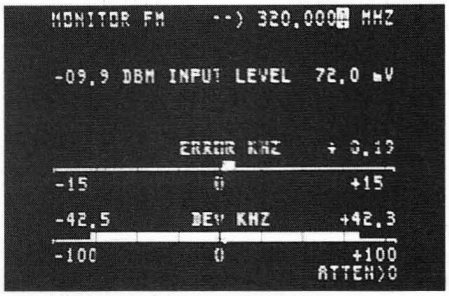



Figure 18c. Modulation Spectrum

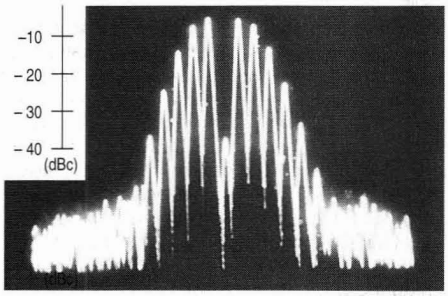
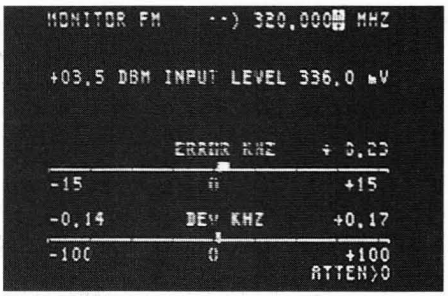



Figure 18d. Unmodulated Carrier

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**Reference Crystal Oscillator (Pins 8 and 9)**

**Selection of Proper Crystal:** A crystal can operate in a number of mechanical modes. The lowest resonant frequency mode is its fundamental while higher order modes are called overtones. At each mechanical resonance, a crystal behaves like a RLC series–tuned circuit having a large inductor and a high Q. The inductor $L_S$ is series resonance with a dynamic capacitor, $C_S$ determined by the elasticity of the crystal lattice and a series resistance $R_S$, which accounts for the power dissipated in heating the crystal. This series RLC circuit is in parallel with a static capacitance, $C_p$ which is created by the crystal block and by the metal plates and leads that make contact with it.

Figure 20 is the equivalent circuit for a crystal in a single resonant mode. It is assumed that other modes of resonance are so far off frequency that their effects are negligible.

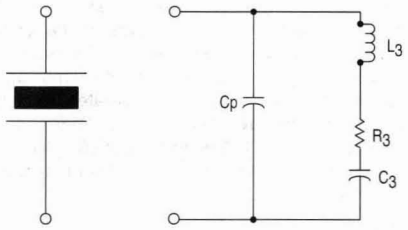
Series resonant frequency, $f_s$ is given by;

$$f_s = 1/2\pi(L_S C_S)^{1/2}$$

and parallel resonant frequency, $f_p$ is given by;

$$f_p = f_s(1 + C_S/C_p)^{1/2}$$

Figure 20. Crystal Equivalent Circuit




the frequency separation at resonance is given by;

$$\Delta f = f_p - f_s = f_s[1 - (1 + C_S/C_p)^{1/2}]$$

Usually $f_p$ is less than 1% higher than $f_s$, and a crystal exhibits an extremely wide variation of the reactance with frequency between $f_p$ and $f_s$. A crystal oscillator circuit is very stable with frequency. This high rate of change of impedance with frequency stabilizes the oscillator, because any significant change in oscillator frequency will cause a large phase shift in the feedback loop keeping the oscillator on frequency.

Manufacturers specify crystal for either series or parallel resonant operation. The frequency for the parallel mode is calibrated with a specified shunt capacitance called a "load capacitance." The most common value is 30 to 32 pF. If the load capacitance is placed in series with the crystal, the equivalent circuit will be series resonance at the specified parallel–resonant frequency. Frequencies up to 20 MHz use parallel resonant crystal operating in the fundamental mode, while above 20 MHz to about 60 MHz, a series resonant crystal specified and calibrated for operation in the overtone mode is used.

**Application Examples**

Two types of crystal oscillator circuits are used in the applications circuits: 1) fundamental mode common emitter Colpitts (Figures 1, 17a, 17b, and 21), and 2) third overtone impedance inversion Colpitts (also Figures 1 and 21).

The fundamental mode common emitter Colpitts uses a parallel resonant crystal calibrated with a 32 pf load capacitance. The capacitance values are chosen to provide excellent frequency stability and output power of > 500 mVp–p at Pin 9. In Figures 1 and 21, the fundamental mode reference oscillator is fixed tuned relying on the repeatability of the crystal and passive network to maintain the frequency, while in the circuit shown in Figure 17, the oscillator frequency can be adjusted with the variable inductor for the precise operating frequency.

The third overtone impedance inversion Colpitts uses a series resonance crystal with a 25 ppm tolerance. In the application examples (Figures 1 and 21), the reference oscillator operates with the third overtone crystal at 40.0000 MHz. Thus, the MC13175 is operated at 320 MHz ($f_O$/8 = crystal; 320/8 = 40.0000 MHz. The resistor across the crystal ensures that the crystal will operate in the series resonant mode. A tuneable inductor is used to adjust the oscillation frequency; it forms a parallel resonant circuit with the series and parallel combination of the external capacitors forming the divider and feedback network and the base–emitter capacitance of the device. If the crystal is shorted, the reference oscillator should free–run at the frequency dictated by the parallel resonant LC network.

The reference oscillator can be operated as high as 60 MHz with a third overtone crystal. Therefore, it is possible to use the MC13175 up to at least 480 MHz and the MC13176 up to 950 MHz (based on the maximum capability of the divider network).

**Enable (Pin 11)**

The enabling resistor at Pin 11 is calculated by:

$$R_{eg.\ enable} = V_{CC} - 1.0\ Vdc / I_{reg.\ enable}$$

From Figure 4, $I_{reg.\ enable}$ is chosen to be 75 µA. So, for a $V_{CC}$ = 3.0 Vdc $R_{reg.\ enable}$ = 26.6 kΩ, a standard value 27 kΩ resistor is adequate.

**Layout Considerations**

**Supply (Pin 12):** In the PCB layout, the $V_{CC}$ trace must be kept as wide as possible to minimize inductive reactance along the trace; it is best that $V_{CC}$ (RF ground) completely fills around the surface mounted components and interconnect traces on the circuit side of the board. This technique is demonstrated in the evaluation PC board.

**Battery/Selection/Lithium Types**

The device may be operated from a 3.0 V lithium battery. Selection of a suitable battery is important. Because one of the major problems for long life battery powered equipment is oxidation of the battery terminals, a battery mounted in a clip–in socket is not advised. The battery leads or contact post should be isolated from the air to eliminate oxide build–up. The battery should have PC board mounting tabs which can be soldered to the PCB. Consideration should be given for the peak current capability of the battery. Lithium batteries have current handling capabilities based on the composition of the lithium compound, construction and the battery size. A 1300 mA/hr rating can be achieved in the cylindrical cell battery. The Rayovac CR2/3A lithium–manganese dioxide battery is a crimp sealed, spiral wound 3.0 Vdc, 1300 mA/hr cylindrical cell with PC board mounting tabs. It is an excellent choice based on capacity and size (1.358″ long by 0.665″ in diameter).

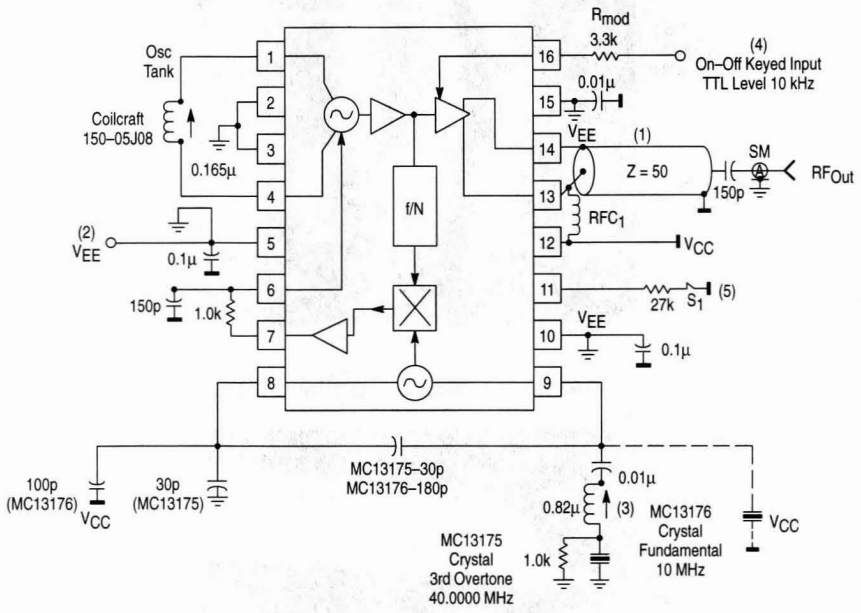
**Differential Output (Pins 13, 14)**

The availability of micro–coaxial cable and small baluns in surface mount and radial–leaded components allows for simple interface to the output ports. A loop antenna may be directly connected with bias via RFC or 50 Ω resistors. Antenna configuration will vary depending on the space available and the frequency of operation.

**AM Modulation (Pin 16)**

**Amplitude Shift Key:** The MC13175 and MC13176 are designed to accommodate Amplitude Shift Keying (ASK). ASK modulation is a form of digital modulation corresponding to AM. The amplitude of the carrier is switched between two or more values in response to the PCM code. For the binary case, the usual choice is On–Off Keying (often abbreviated OOK). The resultant amplitude modulated waveform consists of RF pulses called marks, representing binary 1 and spaces representing binary 0.

**Figure 21. ASK 320 MHz Application Circuit**




**NOTES:** 1. 50 Ω coaxial balun, 1/10 wavelength line (1.5″) provides the best match to a 50 Ω load.

2. Pins 5, 10 and 15 are ground and connnected to $V_{EE}$ which is the component/DC ground plane side of PCB. These pins must be decoupled to $V_{CC}$; decoupling capacitors should be placed as close as possible to the pins.

3. The crystal oscillator circuit may be adjusted for frequency with the variable inductor (MC13175); 1.0 k resistor shunting the crystal prevents it from oscillating in the fundamental mode. Recommended source is Coilcraft "slot seven" 7.0 mm tuneable inductor, part #7M3–821.

4. The On–Off keyed signal turns the output of the transmitter off and on with TTL level pulses through $R_{mod}$ at Pin 16. The "On" power and $I_{CC}$ is set by the resistor which sets $I_{mod}$ = VTTL – 0.8 / $R_{mod}$. (see Figure 23).

5. S1 simulates an enable gate pulse from a microprocessor which will enable the transmitter. (see Figure 4 to determine precise value of the enabling resistor based on the potential of the gate pulse and the desired enable.)

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Figure 21 shows a typical application in which the output power has been reduced for linearity and current drain. The current draw on the device is 16 mA $I_{CC}$ (average) and – 22.5 dBm (average power output) using a 10 kHz modulating rate for the on–off keying. This equates to 20 mA and – 2.3 dBm "On", 13 mA and – 41 dBm "Off". In Figure 22a, the device's modulating waveform and encoded carrier are displayed. The crystal oscillator enable time is needed to set the acquisition timing. It takes typically 4.0 msec to reach full magnitude of the oscillator waveform (see Figure 22b, Oscillator Waveform, at Pin 8). A square waveform of 3.0 V peak with a period that is greater than the oscillator enable time is applied to the Enable (Pin 11).

**Figure 22a. ASK Input Waveform and Modulated Carrier**

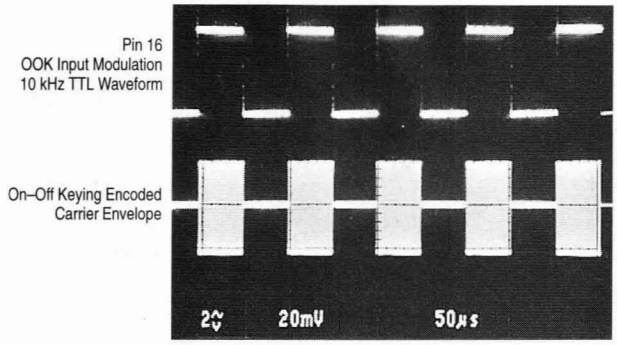


**Figure 22b. Oscillator Enable Time, $T_{enable}$**

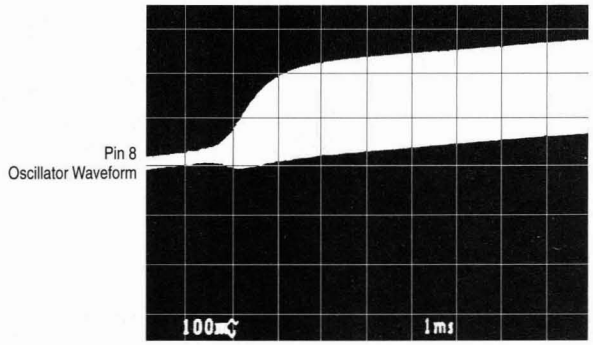


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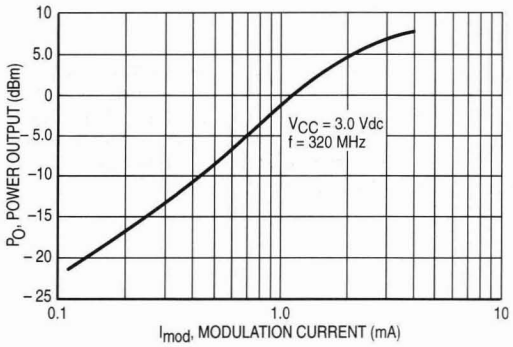
**Figure 23. Power Output versus Modulation Current**




**Analog AM**

In analog AM applications, the output amplifier's linearity must be carefully considered. Figure 23 is a plot of Power Output versus Modulation Current at 320 MHz, 3.0 Vdc. In order to achieve a linear encoding of the modulating sinusoidal waveform on the carrier, the modulating signal must amplitude modulate the carrier in the linear portion of its power output response. When using a sinewave modulating signal, the signal rides on a positive DC offset called $V_{mod}$ which sets a static (modulation off) modulation current, $I_{mod}$. $I_{mod}$ controls the power output of the IC. As the modulating signal moves around this static bias point the modulating current varies causing power output to vary or to be AM modulated. When the IC is operated at modulation current levels greater than 2.0 mAdc the differential output stage starts to saturate.

In the design example, shown in Figure 24, the operating point is selected as a tradeoff between average power output and quality of the AM.

For $V_{CC}$ = 3.0 Vdc; $I_{CC}$ = 18.5 mA and $I_{mod}$ = 0.5 mAdc and a static DC offset of 1.04 Vdc, the circuit shown in Figure 24 completes the design. Figures 25a, 25b and 25c show the results of – 6.9 dBm output power and 100% modulation by the 10 kHz and 1.0 MHz modulating sinewave signals. The amplitude of the input signals is approximately 800 mVp–p.

Where $R_{mod}$ = ($V_{CC}$ – 1.04 Vdc)/0.5 mA = 3.92 k, use a standard value resistor of 3.9 k.

**Figure 24. Analog AM Transmitter**

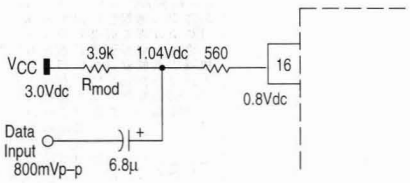



**Figure 25a. Power Output of Unmodulated Carrier**

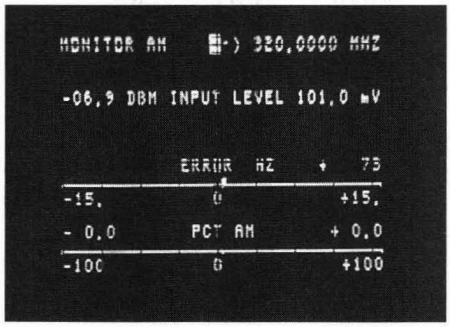



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**Figure 25b. Input Signal and AM Modulated**
Carrier for $f_{mod}$ = 10 kHz

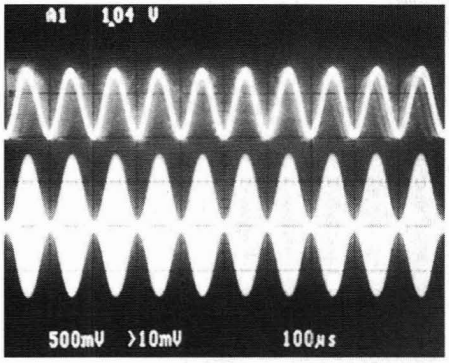



**Figure 25c. Input Signal and AM Modulated**
Carrier for $f_{mod}$ = 1.0 MHz

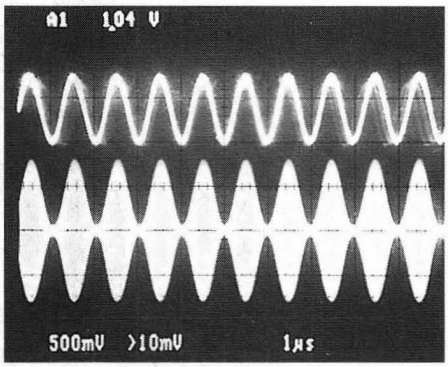


Figure 26. Circuit Side View of MC1317XD

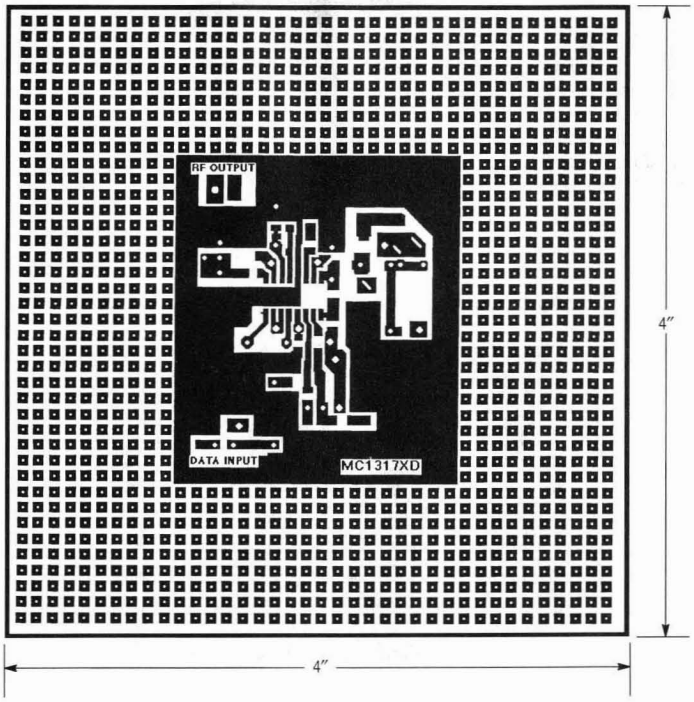





Figure 27. Ground Side View

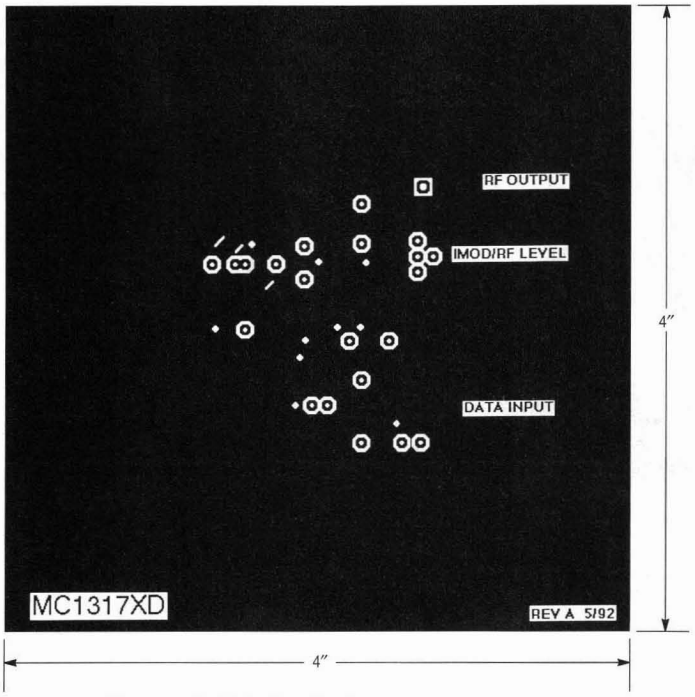


Figure 28. Surface Mounted Components Placement
(on Circuit Side)

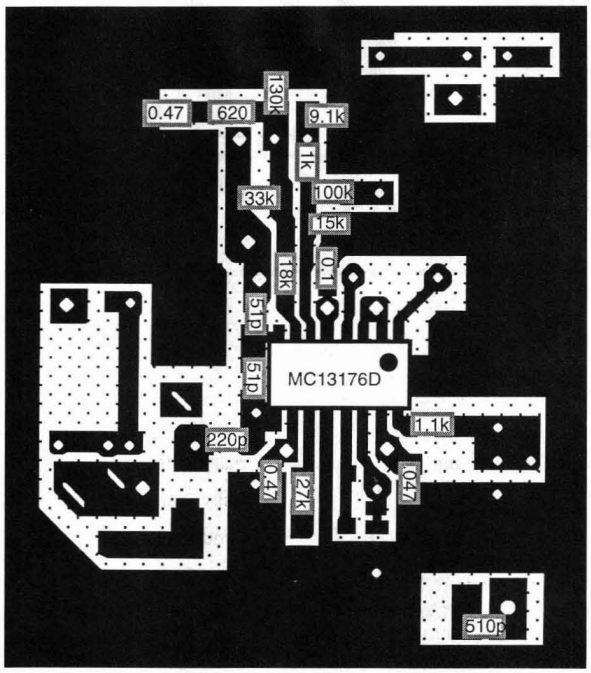
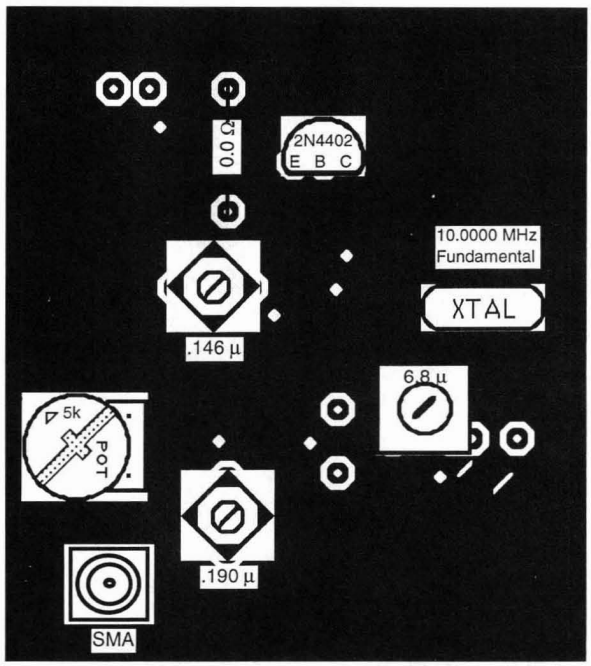



Figure 29. Radial Leaded Components Placement
(on Ground Side)

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# Addendum
# An Introduction to Motorola RF Communications IC Applications

## In Brief . . .

*The RF devices described in Chapter 8 are targeted for the consumer communications market. In addition, most of these parts are capable of superior performance in professional and industrial applications. These devices represent the latest technology in cost effective RF and audio subsystems for cordless telephones (CT-1), RF LANs, land mobile radio, scanners, cellular telephones, remote control spread spectrum, and amateur radio. The purpose of this addendum is to help the user explore all the opportunities presented by this growing family of wireless communications ICs from Motorola Analog.*

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## REGULATORY ISSUES

Each country has its own specific set of regulations regarding radio frequency systems and equipment built and sold within its jurisdiction. These regulations are strongly applicable to transmitting devices. The rules are based on both local needs and international treaties. The regulations are established to provide maximum utilization of the limited available radio spectrum. Motorola strongly recommends that you, the user of these communication ICs, obtain the applicable regulations and abide by them.

In the United States, the regulations of the Federal Communications Commission (F.C.C.) are published in the Code of Federal Regulations (CFR), Title 47, Parts 0 through 99. In the U.S. most of the consumer applications fall under CFR 47, Part 15, covering nonlicensed intentional radiators, or Part 68 which covers public network interconnections. CFR 47 may be obtained at most libraries (in the reference section), or from the U.S. Government Printing Office. You may call their office at (213) 894-5841, or (202) 274-2054 for price and availability. In addition, private contractors such as the Rules Service Company, (301) 424-9402 can provide both the CFR data and an automatic update service. In the U.S., further information is available from the FCC field organization.

For the address and telephone number of the nearest office, contact:

FCC CONSUMER OFFICE AND
SMALL BUSINESS DIVISION
1919 M STREET WEST
WASHINGTON, D.C. 20554
(202) 632-7000

In other countries, the Ministry of Posts or Telecommunications should be contacted. *Motorola Semiconductor does not warrant that the applications shown in this data book meet all the conditions prescribed by government regulations.*

## INDUSTRY STANDARDS

Throughout the world the telecommunications industry has established working standards committees to ensure equipment compatibility by setting minimum standards. These standards also help make the best use of the available radio spectrum. In the U.S., the Electronic Industries Association (E.I.A.) has developed a series of these recommended standards which have become the defacto global guidelines.

The following EIA Standards apply to Frequency Modulation (FM) systems.

| | |
|---|---|
| EIA/TIA-204C | FM/PM RECEIVER STANDARDS |
| EIA/TIA-152B | FM/PM TRANSMITTER STANDARDS |
| EIA/TIA-316B | TEST CONDITIONS, PORTABLE PERSONAL RADIO |

For additional information and pricing, contact the E.I.A. at the following address:

ELECTRONIC INDUSTRIES ASSOCIATION
ENGINEERING DEPARTMENT
2001 EYE STREET N.W.
WASHINGTON, D.C. 20006
(202) 457-4900

## COMMUNICATIONS SYSTEMS

For the most part, the devices described in Chapter 8 use frequency modulation (FM) for both analog voice and data. FM is generally considered the simplest and most cost efficient type of modulation today. FM offers excellent: noise rejection; good sensitivity; reduction of interference due to the FM capture effect; simple circuitry; and an array of test equipment, most of which has spun-off the land mobile market. Direct digital transmission may also be accomplished using Frequency Shift Keying (FSK) or Amplitude Shift Keying (ASK).

The devices shown in Chapter 8 are designed to operate at frequencies below 1.0 GHz (1000 MHz). Today, that frequency range offers the best compromise among performance, complexity and cost. Over the next decade there will be an increasing movement to 1.0 to 3.0 GHz, as the demand for more complex personal communications systems comes on-line. Motorola will add products to its portfolio as these microwave applications become better defined.

Several reference books on Communications Theory and Design are listed below. These books are generally available at major public and university libraries.

*THE RADIO AMATEUR'S HANDBOOK,* American Radio Relay League, Newington, CT.

*MICROWAVE THEORY AND APPLICATIONS,* Steven F. Adam, Hewlett Packard, Prentice Hall.

*SOLID STATE RADIO ENGINEERING,* Herbert L. Krauss, Charles W. Bosdan, F.H. Raab, Wiley 1980.*R*

*F CIRCUIT DESIGN,* Chris Bowick, Howard Sams & Co., 1982.

*INTRODUCTION TO COMMUNICATIONS SYSTEMS,* Ferrel Stremler, Addison Wesley.

*ARRL ANTENNA HANDBOOK,* American Radio Relay League, Newington, CT.

*STANDARD RADIO COMMUNICATIONS MANUAL,* R.H. Kinley, CET, Prentice Hall, 1985.

In addition, you may find very timely design and component information in the following magazines:

*R.F. DESIGN,* Cardiff Publishing (708) 647-0756.
*MICROWAVES AND RF,* Penton Publishing (216) 696-7000.

## PASSIVE COMPONENTS

The availability of passive components; coils, filters, crystals, capacitors, resonators, resistors, etc., is often a larger problem than finding the RF or analog IC to meet a designer's needs. The Motorola applications engineering team considers this a key issue when developing the circuits shown in our data sheets. Analog Applications has worked with many suppliers to develop practical and reasonably priced passive component selections. Suppliers who have a global support structure and can supply both prototype and production quantities are listed. The following table lists a number of suppliers which have been used in recent applications. The design engineer will also need information on the performance of the components as a function of temperature, frequency, solderability and reliability. Most of these suppliers have applications-engineering support with a wealth of specific technical information. *Motorola, however, cannot warrant the suppliers' quality, availability, or prices.*

*Motorola suggests contacting the suppliers directly to obtain technical information and competitive quotes.*

In many cases, recommendations have been made to use readily available sources such as "Radio Shack" for small parts and construction material. The user is encouraged to develop a core of dependable and local, if possible, suppliers for his or her passive components. Please note that many data sheets have specific passive components which have been used to develop and characterize the integrated circuit. Constructing a benchmark circuit with these components is an excellent starting point in the development of a new design.

## COMPONENT SUPPLIERS

*QUARTZ CRYSTALS — FREQUENCY CONTROL:*

| | |
|---|---|
| California Crystal Laboratories | (800) 333-9825 |
| Fox Electronics | (813) 693-0099 |
| International Crystals | (405) 236-3741 |
| Standard Crystal Corporation | (818) 443-2121 |

*GENERAL COMPONENTS — PROTOTYPE QUANTITIES — ASSEMBLY MATERIAL — PC BOARD MATERIAL:*

| | |
|---|---|
| Digi-Key Corporation | (800) 344-4539 |
| Radio Shack Division, Tandy Corporation | (See local telephone directory) |

*INDUCTORS, COILS, RF TRANSFORMERS, FIXED AND VARIABLE:*

| | |
|---|---|
| Coilcraft | (800) 322-COIL<br>(708) 639-6400 |
| Toko America, Inc. | (708) 297-0070 |

*CERAMIC FILTERS AND RESONATORS, IF FILTERS — AM & FM TYPES:*

| | |
|---|---|
| muRata Erie | (404) 436-1300 (Todd Brown, Harry Moore) |
| TDK Corporation of America | (708) 803-6100 |
| Toko America, Inc. | (708) 297-0070 |

## BREADBOARDING

Breadboarding RF or other high speed analog circuits can be a very frustrating process for the newcomer or even an experienced digital designer. Most of these circuits deal with very high gain (100+ dB), very small signals of less than a few microvolts, or with very high frequencies with wavelengths that are a fraction of a meter. Once "friendly" 0.1 μF capacitors may act as inductors, due to their parasitic inductance, while conventional construction methods may yield only circuits that oscillate.

*What to avoid (never use these):*

- — Wire wrap for RF or high frequency breadboards.
- — Conventional push-in prototype boards.
- — Digital printed protoboards with ground and power supply bus lines.

*What to use:*

- — Carefully laid-out double-sided groundplane PC boards.
- — Grid boards with a backside ground plane.
- — Single-sided PC layouts with continuous full ground fill.
- — High frequency qualified components.
- — Adequate decoupling.

The RF designer will find recommended PC board layouts for most of the communications circuits in Chapter 8. These layouts are strongly recommended as starting points for new designs. They will allow you to develop your own benchmark standard circuit to be used as a standard of comparison during further design iterations. Many Motorola communications ICs have supporting development kits which include a PC board. These boards are meant to provide performance equivalent to the data sheet specifications, and are easy to modify for other uses however, these boards are not optimized or intended for production applications. Contact your Motorola sales office or Motorola distributor for information on the availability of these development kits.

In addition, there are many PC and Macintosh-based CAD programs available today. In general, these programs work well for digital and low frequency analog circuits, but are of very limited value in RF applications. SPICE models are not currently available for the communications circuits. Several circuits do show S-Parameter data or admittance plane information which may be used to optimize input or output matching for gain or noise. The most useful method of utilizing the applications circuits at different frequencies is simple linear scaling of the tuning and reactive elements. This method is generally applicable over a 2:1 frequency range lower than the documented application.

Many communication applications include some digital signaling, data conversion, or microcontroller interface. The RF Designer must take great caution to avoid interference with the low level analog circuits in these mixed-mode systems. The receivers are particularly susceptible to interference as they respond to signals of only a few microvolts. Make sure the clock frequency is not a submultiple of the receiver input or IF frequencies. Be sure to keep the dc supply lines for the digital and analog portions separate. Avoid ground paths carrying common digital and analog currents. Common sense as well as analytical skill is required for a successful RF design. A good consultant may well save many times their fee in material, lost time, and rework expenses.

## TEST EQUIPMENT

Establishing a new RF/Communications lab can be a very costly investment. The normal DVMs and regulated power supplies are generally acceptable, if they do not generate spurious RF, and are not sensitive to RF voltages. The Designer should choose an oscilloscope with a frequency response three or more times higher than the operating frequency. In addition, a low capacitance probe, a FET probe, would be useful. Remember, while conventional probes have very high input resistance, their capacitive reactance decreases with frequency and becomes a limiting factor above 30 MHz. For most transmitter work, a basic spectrum analyzer is a must to help confirm power output, spurious output levels, stability, and modulation characteristics.

Rental and used equipment are often a good source of test equipment. Communications System Analysers have recently become available at very moderate prices. The Motorola R2600, for example, combines 16 different instruments into one portable package. The signal generator, receiver, counter, oscilloscope and a "best-in-class" modulation meter make this instrument a very attractive design and production test tool. Further information, including a demonstration, are available from your local Motorola Communications and Electronics sales office.

## WORLDWIDE CORDLESS TELEPHONE FREQUENCIES

The following tables contain CT–1 USA and Asia Pacific (CT–0 Europe) frequencies for cordless telephone. These tables reference application information provided in MC13109, MC13110, and MC13111 Universal Cordless Telephone Subsystem Integrated Circuit Technical Data Sheets. Channel number, $T_X$ channel frequency, 1st LO frequency, and $T_X$ and $R_X$ divider values are listed in this addendum. The device data sheets can be found in Chapter 8 of this Data Book (DL128).

Note: USA cordless frequency band listed herein is specified in the Code of Federal Regulations (CFR), Title 47 (FCC Rules), Part 15, paragraph 15.233, dated June 5, 1995 (25 channel band).

### CHANNEL FREQUENCIES

**USA CT–1 BASESET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 43.720 | 8744 | 38.065 | 7613 |
| 2 | 43.740 | 8748 | 38.145 | 7629 |
| 3 | 43.820 | 8764 | 38.165 | 7633 |
| 4 | 43.840 | 8768 | 38.225 | 7645 |
| 5 | 43.920 | 8784 | 38.325 | 7665 |
| 6 | 43.960 | 8792 | 38.385 | 7677 |
| 7 | 44.120 | 8824 | 38.405 | 7681 |
| 8 | 44.160 | 8832 | 38.465 | 7693 |
| 9 | 44.180 | 8836 | 38.505 | 7701 |
| 10 | 44.200 | 8840 | 38.545 | 7709 |
| 11 | 44.320 | 8864 | 38.585 | 7717 |
| 12 | 44,360 | 8872 | 38.665 | 7733 |
| 13 | 44.400 | 8880 | 38.705 | 7741 |
| 14 | 44.460 | 8892 | 38.765 | 7753 |
| 15 | 44.480 | 8896 | 38.805 | 7761 |
| 16 | 46.610 | 9322 | 38.975 | 7795 |
| 17 | 46.630 | 9326 | 39.150 | 7830 |
| 18 | 46.670 | 9334 | 39.165 | 7833 |
| 19 | 46.710 | 9342 | 39.075 | 7815 |
| 20 | 46.730 | 9346 | 39.180 | 7836 |
| 21 | 46.770 | 9354 | 39.135 | 7827 |
| 22 | 46.830 | 9366 | 39.195 | 7839 |
| 23 | 46.870 | 9374 | 39.235 | 7847 |
| 24 | 46.930 | 9386 | 39.295 | 7859 |
| 25 | 46.970 | 9394 | 39.275 | 7855 |

## USA CT–1 HANDSET CHANNEL FREQUENCIES (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 48.760 | 9752 | 33.025 | 6605 |
| 2 | 48.840 | 9768 | 33.045 | 6609 |
| 3 | 48.860 | 9772 | 33.125 | 6625 |
| 4 | 48.920 | 9784 | 33.145 | 6629 |
| 5 | 49.020 | 9804 | 33.225 | 6645 |
| 6 | 49.080 | 9816 | 33.265 | 6653 |
| 7 | 49.100 | 9820 | 33.425 | 6685 |
| 8 | 49.160 | 9832 | 33.465 | 6693 |
| 9 | 49.200 | 9840 | 33.485 | 6697 |
| 10 | 49.240 | 9848 | 33.505 | 6701 |
| 11 | 49.280 | 9856 | 33.625 | 6725 |
| 12 | 49.360 | 9872 | 33.665 | 6733 |
| 13 | 49.400 | 9880 | 33.705 | 6741 |
| 14 | 49.460 | 9892 | 33.765 | 6753 |
| 15 | 49.500 | 9900 | 33.785 | 6757 |
| 16 | 49.670 | 9934 | 35.915 | 7183 |
| 17 | 49.845 | 9969 | 35.935 | 7187 |
| 18 | 49.860 | 9972 | 35.975 | 7195 |
| 19 | 49.770 | 9954 | 36.015 | 7203 |
| 20 | 49.875 | 9975 | 36.035 | 7207 |
| 21 | 49.830 | 9966 | 36.075 | 7215 |
| 22 | 49.890 | 9978 | 36.135 | 7227 |
| 23 | 49.930 | 9986 | 36.175 | 7235 |
| 24 | 49.990 | 9998 | 36.235 | 7247 |
| 25 | 49.970 | 9994 | 36.275 | 7255 |

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## SPAIN CT–1 BASESET CHANNEL FREQUENCIES (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 31.025 | 6205 | 29.230 | 5846 |
| 2 | 31.050 | 6210 | 29.255 | 5851 |
| 3 | 31.075 | 6215 | 29.280 | 5856 |
| 4 | 31.100 | 6220 | 29.305 | 5861 |
| 5 | 31.125 | 6225 | 29.330 | 5866 |
| 6 | 31.150 | 6230 | 29.355 | 5871 |
| 7 | 31.175 | 6235 | 29.380 | 5876 |
| 8 | 31.200 | 6240 | 29.405 | 5881 |
| 9 | 31.250 | 6250 | 29.455 | 5891 |
| 10 | 31.275 | 6255 | 29.480 | 5896 |
| 11 | 31.300 | 6260 | 29.505 | 5901 |
| 12 | 31.325 | 6265 | 29.530 | 5906 |

**SPAIN CT–1 HANDSET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 39.925 | 7985 | 20.330 | 4066 |
| 2 | 39.950 | 7990 | 20.355 | 4071 |
| 3 | 39.975 | 7995 | 20.380 | 4076 |
| 4 | 40.000 | 8000 | 20.405 | 4081 |
| 5 | 40.025 | 8005 | 20.430 | 4086 |
| 6 | 40.050 | 8010 | 20.455 | 4091 |
| 7 | 40.075 | 8015 | 20.480 | 4096 |
| 8 | 40.100 | 8020 | 20.505 | 4101 |
| 9 | 40.150 | 8030 | 20.555 | 4111 |
| 10 | 40.175 | 8035 | 20.580 | 4116 |
| 11 | 40.200 | 8040 | 20.605 | 4121 |
| 12 | 40.225 | 8045 | 20.630 | 4126 |

**AUSTRALIA CT–1 BASESET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 30.075 | 6015 | 29.080 | 5816 |
| 2 | 30.125 | 6025 | 29.130 | 5826 |
| 3 | 30.175 | 6035 | 29.180 | 5836 |
| 4 | 30.225 | 6045 | 29.230 | 5846 |
| 5 | 30.275 | 6055 | 29.280 | 5856 |
| 6 | 30.100 | 6020 | 29.105 | 5821 |
| 7 | 30.150 | 6030 | 29.155 | 5831 |
| 8 | 30.200 | 6040 | 29.205 | 5841 |
| 9 | 30.250 | 6050 | 29.255 | 5851 |
| 10 | 30.300 | 6060 | 29.305 | 5861 |

**AUSTRALIA CT–1 HANDSET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 39.775 | 7955 | 19.380 | 3876 |
| 2 | 39.825 | 7965 | 19.430 | 3886 |
| 3 | 39.875 | 7975 | 19.480 | 3896 |
| 4 | 39.925 | 7985 | 19.530 | 3906 |
| 5 | 39.975 | 7995 | 19.580 | 3916 |
| 6 | 39.800 | 7960 | 19.405 | 3881 |
| 7 | 39.850 | 7970 | 19.455 | 3891 |
| 8 | 39.900 | 7980 | 19.505 | 3901 |
| 9 | 39.950 | 7990 | 19.555 | 3911 |
| 10 | 40.000 | 8000 | 19.605 | 3921 |

**KOREA CT–1 BASESET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 46.610 | 9322 | 38.975 | 7795 |
| 2 | 46.630 | 9326 | 39.150 | 7830 |
| 3 | 46.670 | 9334 | 39.165 | 7833 |
| 4 | 46.710 | 9342 | 39.075 | 7815 |
| 5 | 46.730 | 9346 | 39.180 | 7836 |
| 6 | 46.770 | 9354 | 39.135 | 7827 |
| 7 | 46.830 | 9366 | 39.195 | 7839 |
| 8 | 46.870 | 9374 | 39.235 | 7847 |
| 9 | 46.930 | 9386 | 39.295 | 7859 |
| 10 | 46.970 | 9394 | 39.275 | 7855 |
| 11 | 46.510 | 9302 | 39.000 | 7800 |
| 12 | 46.530 | 9306 | 39.015 | 7803 |
| 13 | 46.550 | 9310 | 39.030 | 7806 |
| 14 | 46.570 | 9314 | 39.045 | 7809 |
| 15 | 46.590 | 9318 | 39.060 | 7812 |

**KOREA CT–1 HANDSET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 49.670 | 9934 | 35.915 | 7183 |
| 2 | 49.845 | 9969 | 35.935 | 7187 |
| 3 | 49.860 | 9972 | 35.975 | 7195 |
| 4 | 49.770 | 9954 | 36.015 | 7203 |
| 5 | 49.875 | 9975 | 36.035 | 7207 |
| 6 | 49.830 | 9966 | 36.075 | 7215 |
| 7 | 49.890 | 9978 | 36.135 | 7227 |
| 8 | 49.930 | 9986 | 36.175 | 7235 |
| 9 | 49.990 | 9998 | 36.235 | 7247 |
| 10 | 49.970 | 9994 | 36.275 | 7255 |
| 11 | 49.695 | 9939 | 35.815 | 7163 |
| 12 | 49.710 | 9942 | 35.835 | 7167 |
| 13 | 49.725 | 9945 | 35.855 | 7171 |
| 14 | 49.740 | 9948 | 35.875 | 7175 |
| 15 | 49.755 | 9951 | 35.895 | 7179 |

**NEW ZEALAND CT–1 BASESET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_x$ Channel Frequency (MHz) | $T_x$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_x$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 11 | 34.250 | 6850 | 29.555 | 5911 |
| 12 | 34.275 | 6855 | 29.580 | 5916 |
| 13 | 34.300 | 6860 | 29.605 | 5921 |
| 14 | 34.325 | 6865 | 29.630 | 5926 |
| 15 | 34.350 | 6870 | 29.655 | 5931 |
| 16 | 34.375 | 6875 | 29.680 | 5936 |
| 17 | 34.400 | 6880 | 29.705 | 5941 |
| 18 | 34.425 | 6885 | 29.730 | 5946 |
| 19 | 34.450 | 6890 | 29.755 | 5951 |
| 20 | 34.475 | 6895 | 29.780 | 5956 |

**NEW ZEALAND CT–1 HANDSET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_x$ Channel Frequency (MHz) | $T_x$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_x$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 11 | 40.250 | 8050 | 23.555 | 4711 |
| 12 | 40.275 | 8055 | 23.580 | 4716 |
| 13 | 40.300 | 8060 | 23.605 | 4721 |
| 14 | 40.325 | 8065 | 23.630 | 4726 |
| 15 | 40.350 | 8070 | 23.655 | 4731 |
| 16 | 40.375 | 8075 | 23.680 | 4736 |
| 17 | 40.400 | 8080 | 23.705 | 4741 |
| 18 | 40.425 | 8085 | 23.730 | 4746 |
| 19 | 40.450 | 8090 | 23.755 | 4751 |
| 20 | 40.475 | 8095 | 23.780 | 4756 |

**U.K. BASESET CHANNEL FREQUENCIES** (2nd LO = 11.150 MHz, Ref Divider = 446 + divide by 4/25)

| Channel Number | $T_x$ Channel Frequency (MHz) | $T_x$ Divider (1.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.7 MHz | $R_x$ Divider (6.25 kHz Ref) |
|---|---|---|---|---|
| 1 | 1.642 | 1642 | 36.75625 | 5881 |
| 2 | 1.662 | 1662 | 36.76875 | 5883 |
| 3 | 1.682 | 1682 | 36.78125 | 5885 |
| 4 | 1.702 | 1702 | 36.79375 | 5887 |
| 5 | 1.722 | 1722 | 36.80625 | 5889 |
| 6 | 1.742 | 1742 | 36.81875 | 5891 |
| 7 | 1.762 | 1762 | 36.83125 | 5893 |
| 8 | 1.782 | 1782 | 36.84375 | 5895 |

**U.K. HANDSET CHANNEL FREQUENCIES** (2nd LO = 11.150 MHz, Ref Divider = 446 + divide by 4/25)

| Channel Number | $T_x$ Channel Frequency (MHz) | $T_x$ Divider (6.25 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.7 MHz | $R_x$ Divider (1.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 47.45625 | 7593 | 12.342 | 12342 |
| 2 | 47.46875 | 7595 | 12.362 | 12362 |
| 3 | 47.48125 | 7597 | 12.382 | 12382 |
| 4 | 47.49375 | 7599 | 12.402 | 12402 |
| 5 | 47.50625 | 7601 | 12.422 | 12422 |
| 6 | 47.51875 | 7603 | 12.442 | 12442 |
| 7 | 47.53125 | 7605 | 12.462 | 12462 |
| 8 | 47.54375 | 7607 | 12.482 | 12482 |

**FRANCE BASESET CHANNEL FREQUENCIES** (2nd LO = 11.150 MHz, Ref Divider = 1784)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (6.25 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.7 MHz | $R_X$ Divider (6.25 kHz Ref) |
|---|---|---|---|---|
| 1 | 26.3125 | 4210 | 30.6125 | 4898 |
| 2 | 26.3250 | 4212 | 30.6250 | 4900 |
| 3 | 26.3375 | 4214 | 30.6375 | 4902 |
| 4 | 26.3500 | 4216 | 30.6500 | 4904 |
| 5 | 26.3625 | 4218 | 30.6625 | 4906 |
| 6 | 26.3750 | 4220 | 30.6750 | 4908 |
| 7 | 26.3875 | 4222 | 30.6875 | 4910 |
| 8 | 26.4000 | 4224 | 30.7000 | 4912 |
| 9 | 26.4125 | 4226 | 30.7125 | 4914 |
| 10 | 26.4250 | 4228 | 30.7250 | 4916 |
| 11 | 26.4375 | 4230 | 30.7375 | 4918 |
| 12 | 26.4500 | 4232 | 30.7500 | 4920 |
| 13 | 26.4625 | 4234 | 30.7625 | 4922 |
| 14 | 26.4750 | 4236 | 30.7750 | 4924 |
| 15 | 26.4875 | 4238 | 30.7875 | 4926 |

**FRANCE HANDSET CHANNEL FREQUENCIES** (2nd LO = 11.150 MHz, Ref Divider = 1784)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (6.25 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.7 MHz | $R_X$ Divider (6.25 kHz Ref) |
|---|---|---|---|---|
| 1 | 41.3125 | 6610 | 37.0125 | 5922 |
| 2 | 41.3250 | 6612 | 37.0250 | 5924 |
| 3 | 41.3375 | 6614 | 37.0375 | 5926 |
| 4 | 41.3500 | 6616 | 37.0500 | 5928 |
| 5 | 41.3625 | 6618 | 37.0625 | 5930 |
| 6 | 41.3750 | 6620 | 37.0750 | 5932 |
| 7 | 41.3875 | 6622 | 37.0875 | 5934 |
| 8 | 41.4000 | 6624 | 37.1000 | 5936 |
| 9 | 41.4125 | 6626 | 37.1125 | 5938 |
| 10 | 41.4250 | 6628 | 37.1250 | 5940 |
| 11 | 41.4375 | 6630 | 37.1375 | 5942 |
| 12 | 41.4500 | 6632 | 37.1500 | 5944 |
| 13 | 41.4625 | 6634 | 37.1625 | 5946 |
| 14 | 41.4750 | 6636 | 37.1750 | 5948 |
| 15 | 41.4875 | 6638 | 37.1875 | 5950 |

**CHINA BASESET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 45.250 | 9050 | 37.555 | 7511 |
| 2 | 45.275 | 9055 | 37.580 | 7516 |
| 3 | 45.300 | 9060 | 37.605 | 7521 |
| 4 | 45.325 | 9065 | 37.630 | 7526 |
| 5 | 45.350 | 9070 | 37.655 | 7531 |
| 6 | 45.375 | 9075 | 37.680 | 7536 |
| 7 | 45.400 | 9080 | 37.705 | 7541 |
| 8 | 45.425 | 9085 | 37.730 | 7546 |
| 9 | 45.450 | 9090 | 37.755 | 7551 |
| 10 | 45.475 | 9095 | 37.780 | 7556 |

**CHINA HANDSET CHANNEL FREQUENCIES** (2nd LO = 10.240 MHz, Ref Divider = 2048)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (5.0 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (5.0 kHz Ref) |
|---|---|---|---|---|
| 1 | 48.250 | 9650 | 34.555 | 6911 |
| 2 | 48.275 | 9655 | 34.580 | 6916 |
| 3 | 48.300 | 9660 | 34.605 | 6921 |
| 4 | 48.325 | 9665 | 34.630 | 6926 |
| 5 | 48.350 | 9670 | 34.655 | 6931 |
| 6 | 48.375 | 9675 | 34.680 | 6936 |
| 7 | 48.400 | 9680 | 34.705 | 6941 |
| 8 | 48.425 | 9685 | 34.730 | 6946 |
| 9 | 48.450 | 9690 | 34.755 | 6951 |
| 10 | 48.475 | 9695 | 34.780 | 6956 |

## NETHERLANDS CT–1 BASESET CHANNEL FREQUENCIES

(2nd LO = 10.240 MHz, Ref Divider = 1024 + divide by 4, 2nd IF = 455 Hz)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (2.5 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (2.5 kHz Ref) |
|---|---|---|---|---|
| 1 | 31.0375 | 12415 | 29.2425 | 11697 |
| 2 | 31.0625 | 12425 | 29.2675 | 11707 |
| 3 | 31.0875 | 12435 | 29.2925 | 11717 |
| 4 | 31.1125 | 12445 | 29.3175 | 11727 |
| 5 | 31.1375 | 12455 | 29.3425 | 11737 |
| 6 | 31.1625 | 12465 | 29.3675 | 11747 |
| 7 | 31.1875 | 12475 | 29.3925 | 11757 |
| 8 | 31.2125 | 12485 | 29.4175 | 11767 |
| 9 | 31.2375 | 12495 | 29.4425 | 11777 |
| 10 | 31.2625 | 12505 | 29.4675 | 11787 |
| 11 | 31.2875 | 12515 | 29.4925 | 11797 |
| 12 | 31.3125 | 12525 | 29.5175 | 11807 |

## NETHERLANDS CT–1 HANDSET CHANNEL FREQUENCIES

(2nd LO = 10.240 MHz, Ref Divider = 1024 + divide by 4, 2nd IF = 455 Hz)

| Channel Number | $T_X$ Channel Frequency (MHz) | $T_X$ Divider (2.5 kHz Ref) | 1st LO Frequency (MHz) 1st IF = 10.695 MHz | $R_X$ Divider (2.5 kHz Ref) |
|---|---|---|---|---|
| 1 | 39.9375 | 15975 | 20.3425 | 8137 |
| 2 | 39.9625 | 15985 | 20.3675 | 8147 |
| 3 | 39.9875 | 15995 | 20.3925 | 8157 |
| 4 | 40.0125 | 16005 | 20.4175 | 8167 |
| 5 | 40.0375 | 16015 | 20.4425 | 8177 |
| 6 | 40.0625 | 16025 | 20.4675 | 8187 |
| 7 | 40.0875 | 16035 | 20.4925 | 8197 |
| 8 | 40.1125 | 16045 | 20.5175 | 8207 |
| 9 | 40.1375 | 16055 | 20.5425 | 8217 |
| 10 | 40.1625 | 16065 | 20.5675 | 8227 |
| 11 | 40.1875 | 16075 | 20.5925 | 8237 |
| 12 | 40.2125 | 16085 | 20.6175 | 8247 |

# Consumer Electronic Circuits

## In Brief . . .

These integrated circuits reflect Motorola's continuing commitment to semiconductor products necessary for consumer system designs. This tabulation is arranged to simplify selection of consumer integrated circuit devices that satisfy the primary functions for home entertainment products, including television, hi–fi audio and AM/FM radio.


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# Entertainment Radio Receiver Circuits

### Table 1. Entertainment Receiver RF/IF

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| E.T.R. Front End | Mixer/VCO/AGC for Electronically Tuned AM Stereo Receivers | P/648, D/751B | MC13025 |
| AMAX Front End | Mixer/VCO/AGC with RF and Audio Noise Blanking | DW/751D, P/738 | MC13027 |
| Dual Conversion AM Receiver | 1st Mixer/OSC, 2nd Mixer/OSC, High Gain IF, AGC, Detector | DW/751F | MC13030 |

### Table 2. C–Quam® AM Stereo Decoders

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| Basic AM Stereo Decoder | Monaural/Stereo AM Detector/Indicator, 6.0 to 10 V Operation | P/738 | MC13020 |
| Advanced AM Stereo Decoder | Medium Voltage 4.0 to 10 V, Decoder and IF Amp | P/710, DW/751F | MC13022 |
| Advanced AM Stereo Decoder | Medium Voltage 6.0 to 10 V, Decoder and IF Amp | P/710, DW/751F | MC13022A |
| Low V AM Stereo Receiver | IF/Decoder for Advanced C–Quam Receivers | P/648, D/751B | MC13028A |
| Medium V AM Stereo Decoder | IF/Decoder for Advanced C–Quam Receivers with AM/FM Switch | DW/751D, H/738 | MC13029A |
| AMAX Stereo Decoder | Am Stereo Decoder with Audio Noise Blanker | DW/751F, P/710 | MC13122 |

### Table 3. Audio Amplifiers

| Function | $P_O$ (Watts) | $V_{CC}$ Vdc Max | $V_{in}$ @ Rated $P_O$ mV Typ | $I_D$ mA Typ | $R_L$ (Ohms) | Suffix/ Package | Device |
|---|---|---|---|---|---|---|---|
| Mini Watt SOIC Audio Amp | 1.0 W | 35 | 80 | 11 | 16 | D/751 | MC13060 |
| Low Power Audio Amp | 500 mW | 16 | – | 2.5 mA | $8-\infty$ | D/751, P/626, DTB/948J | MC34119 |

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# Video Circuits

## Table 4. Video Circuits

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| **Encoders** | | | |
| RGB to PAL/NTSC Encoder | RGB and Sync inputs, Composite Video out; PAL/NTSC selectable. | P/738, DW/751D | MC1377 |
| Video Overlay Synchronizer | Complete Color TV Video Overlay Synchronizer, remote or local system control and RGB encoder. | P/711, FN/777 | MC1378 |
| Advanced RGB to PAL/NTSC Encoder | RGB and Sync inputs, Composite Video and S–VHS out; PAL/NTSC selectable; subcarrier from crystal or external source. | P/738, DW/751D | MC13077 |
| **TV Decoder** | | | |
| Chroma 4 Multistandard Decoders (TV Set) | PAL/NTSC/SECAM decoding, Composite Video/S–VHS Inputs, RGB Outputs, horizontal and vertical drive outputs, geometry correction and beam current monitor, digital internal filters, no external tank, 16:9 capability, μP and crystal controlled. | P/711 | MC44002 |
| | Same as MC44002, but without SECAM decoding. | P/711 | MC44007 |
| | Same as MC44002, but with internal chroma delay line. | P/711 | MC44030 |
| | Same as MC44030, but without SECAM decoding. | P/711 | MC44035 |
| **Video Capture Chip Sets** | | | |
| Chroma 4 Multistandard Video Processor (Multimedia) | PAL/NTSC/S–VHS input, RGB/YUV outputs; horizontal and vertical timing outputs; all digital internal filters, no external tanks; μP and crystal controlled. | FN/777, FB/824E | MC44011 |
| Chroma Digital Delay Line | For PAL and SECAM applications of the MC44011, MC44002, MC44007. | P/648, DW/751G | MC44140 |
| Pixel Clock PLL/Sync Sep. | PAL/NTSC sync separator, 6.0–40 MHz pixel clock PLL. | D/751A | MC44145 |
| Triple 8–Bit Video DAC | TTL inputs, 75 Ω drive outputs. | FB/824A | MC44200 |
| Triple 8–Bit Video A/D | Video clamps for RGB/YUV, 18 MHz, High Z TTL outputs. | FN/777 | MC44251 |
| **TV Picture–in–Picture** | | | |
| Picture–in–Picture (PIP) Controller | Completely self–contained NTSC picture–in–picture function. | B/859 | MC44461 |
| Y–C Picture–in–Picture (PIP) Controller | Completely self–contained NTSC picture–in–picture function, with Y–C input and output capability, for use in high performance S–Video systems. | B/859 | MC44462 |
| Replay and Multiple Picture–in–Picture (PIP) Controller | Offers either multiple PIP windows or several seconds of replay. Used with external DRAM. | B/859 | MC44463 |
| **Comb Filters** | | | |
| Enhanced Comb Filter | Fast 8–Bit A/D Converter, Two 8–Bit D/A Converters, Two Line–Delay Memories, utilizes NTSC Subcarrier Frequency clock, CMOS Technology. | FU/898 | MC141620 |
| Advanced Comb Filter (ACF) | Composite Video input; YC outputs in digital and analog form; all digital internal filters. | FU/898 | MC141621A |
| Advanced Comb Filter – II (ACF–II) | Composite Video input; YC outputs in digital and analog form; all digital internal filters; vertical enhancer circuit. | P/898 | MC141622A |
| Advanced Comb Filter – I (ACF–I) | Low cost Ih filter. | FU/873 SP/TBD | MC141624 |
| Advanced PAL/NTSC Comb Filter | Composite Video input; YC outputs in digital and analog form; all digital internal filters. | FB/898 | MC141627 |
| **Deflection** | | | |
| Horizontal Processor | Linear balanced phase detector, oscillator and predriver, adjustable DC loop gain and duty cycle. | P/626 | MC1391 |
| **TV IF Circuits** | | | |
| IF Amplifier | 1st and 2nd video IF amplifiers, 50 dB gain at 45 MHz, 60 dB AGC range. | D/751, P/626 | MC1350 |

## Table 4. Video Circuits (continued)

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| **Tuner PLL Circuits** | | | |
| PLL Tuning Circuits | 1.3 GHz, 10 mV sensitivity selectable prescaler (MC44817), op amp, 4 band buffers, 3–wire bus interface, lock detect. | D/751B | MC44817, B |
| | 1.3 GHz, 10 mV sensitivity prescaler, op amp, 4 band buffers, $I^2C$ interface, lock detect. | D/751B | MC44818 |
| | 1.3 GHz, 10 mV sensitivity prescaler, 3 band buffers, $I^2C$ interface, replacement for Siemens MPG3002. | D/751, D/751B | MC44824, MC44825 |
| | Similar to MC44817, with lower power consumption, push–pull lock detector output, no divide–by–8 bypass, in a TSSOP package. | DTB/948F | MC44827 |
| | Similar to MC44818, with lower power consumption, push–pull lock detector output, in a TSSOP package. | DTB/948F | MC44828 |
| | 1.3 GHz prescaler, 10 mV sensitivity 50 to 950 MHz, op amp, 3 band buffers, Mixer/Osc Decoder and $I^2C$ Bus. | D/751A | MC44829 |
| | 1.3 GHz, 10 mV sensitivity selectable prescaler, op amp, 4 band buffers, $I^2C$ interface, 3 DACs for automatic tuner alignment. | M/967 | MC44864 |
| **Modulator** | | | |
| Color TV Modulator with Sound | RF oscillator/modulator, and FM sound oscillator/modulator. | P/646 | MC1374 |
| UHF TV Modulator | Multi–standard PLL tuned UHF TV modulator with AM or FM sound. | DTB/948E, DW/751D | MC44353, MC44354, MC44355 |
| **Video Data Converters** | | | |
| Single Channel A/D | 8–Bit, 25 MHz, 2.0 V input range, ±5.0 V supplies, TTL output, no pipeline delay. | P/709, DW/751E | MC10319 |
| Triple 8–Bit Video A/D | Video clamps for RGB/YUV, 18 MHz conversion, high Z outputs. | FN/777 | MC44251 |
| Triple 8–Bit Video DAC | TTL inputs, 75 Ω drive outputs. | FB/824 | MC44200 |
| **Monitor Subsystem** | | | |
| Multimode Color Monitor Processor | Adaptable to 30 kHz to 64 kHz horizontal, 45 to 100 Hz vertical frequency, multiple sync including sync–on–green, horizontal and vertical drive outputs, double PLL, 70 MHz RGB pre–amps, contrast and brightness controls. | B/859 | MC13081X |
| RGB Video Processor | 80 MHz bandwidth, blank and clamp inputs, main contrast and subcontrast controls. | P/738 | MC13280AY |
| | Same as above, except 100 MHz bandwidth. | P/738 | MC13281B |
| | Same as above, except 100 MHz bandwidth and pin compatible with MC13282A. | P/724 | MC13281A |
| RGB Video Processor with OSD Inputs | 100 MHz bandwidth, blank and clamp inputs, main contrast and subcontrast controls, OSD inputs, OSD contrast control, pin compatible with MC13281A. | P/724 | MC13282A |
| | Same as above, except 130 MHz bandwidth. | P/724 | MC13283 |
| **Sound** | | | |
| Sound IF Detector | Interchangeable with ULN2111A. | P/646, D/751A | MC1357 |
| **Miscellaneous** | | | |
| Subcarrier Reference Generator | Provides continuous subcarrier sine wave and 4x subcarrier, locked to incoming burst. | P/626, D/751 | MC44144 |
| Closed Caption Decoder | Conforms to FCC, NTSC standards, underline and italics control. | P/707 | MC144143 |
| Enhanced Closed Caption Decoder | Conforms to FCC, NTSC, XDS standards, underline, italics and OSC. | P/707 | MC144144 |
| Sync Separator/Pixel Clock PLL | PAL/NTSC sync separator with vertical and composite sync output, 6 to 40 MHz pixel clock PLL. | D/751A | MC44145 |
| Dual Video Amplifiers | Gain @ 4.43 MHz = 6.0 dB ±1.0 dB, fixed gain, internally compensated, CMOS Technology. | P/626, F/904 | MC14576C |
| | Gain @ 5.0 MHz = 10 dB max, 10 MHz = 6.0 dB max, adjustable gain, internally compensated, CMOS Technology. | P/626, F/904 | MC14577C |

## Table 4. Video Circuits (continued)

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| **Miscellaneous** | | | |
| Transistor Array | One differential pair and 3 isolated transistors, 15 V, 50 mA. | P/646, D/751A | MC3346 |
| General Purpose Transistor Array | One differential pair and 3 isolated transistors, 130 V, 50 mA. | D/751A | CA3146 |

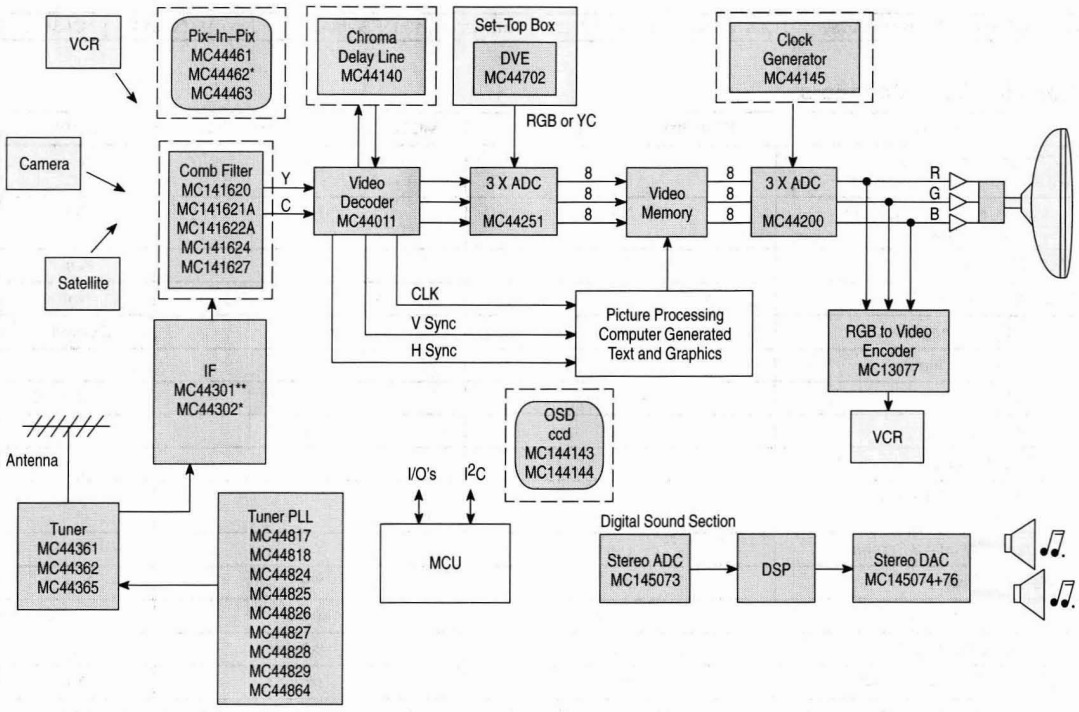
## Table 5. Video Decoders

| Function | MC44002 | MC44007 | MC44030(1) | MC44035 | MC44011 |
|---|---|---|---|---|---|
| For TV Set Applications (RGB Outputs for CRT Driver) | Yes | | Yes | | No |
| For Video Capture Applications (RGB/YUV Outputs) | No | | No | | Yes |
| PAL/NTSC Decoding | Yes | | Yes | | Yes |
| SECAM Decoding | Yes | No | Yes | No | No |
| Chroma Delay Line | External | | Internal | | External |
| Composite Video Inputs | 2 | | 2 | | 2 |
| Y/C Inputs | 1 set (Note 2) | | 1 set (Note 2) | | 1 set (Note 2) |
| RGB Inputs (3 Pins) | 1 set | | 1 set | | 1 set |
| YUV Outputs/Inputs | Yes | | Yes | | Yes |
| Video Output for Teletext or Closed Caption | No | | No | | No |
| 16:9 Capability on 4:3 Screen | Yes | | Yes | | No |
| Single 5.0 V Supply | Yes | | Yes | | Yes |
| Supply Current (Typical) | 120 mA | | 150 mA | | 110 mA |
| Video Mute (Blanking Control) | No | | Yes | | No |
| Pixel Clock Generator for A/D | No | | No | | Yes |

**NOTES:** 1. The MC44030 with integrated chroma delay line can replace the MC44002 + MC44140. A single PC board pattern can be made to accept either device and the software can be written to be compatible, although the MC44030 has several additional functions.
2. In Y/C mode the two CVBS inputs become Y and C inputs.
3. One set uses SCART Video input as Y and SCART Red input as C. The second set are independent inputs.

## Video Circuits (continued)

**Video Capture Block Diagram**




* In Development
** Not recommended for new designs.

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# Digitally Controlled Video Processor for Multimedia Applications

**MC44011FN, FB**

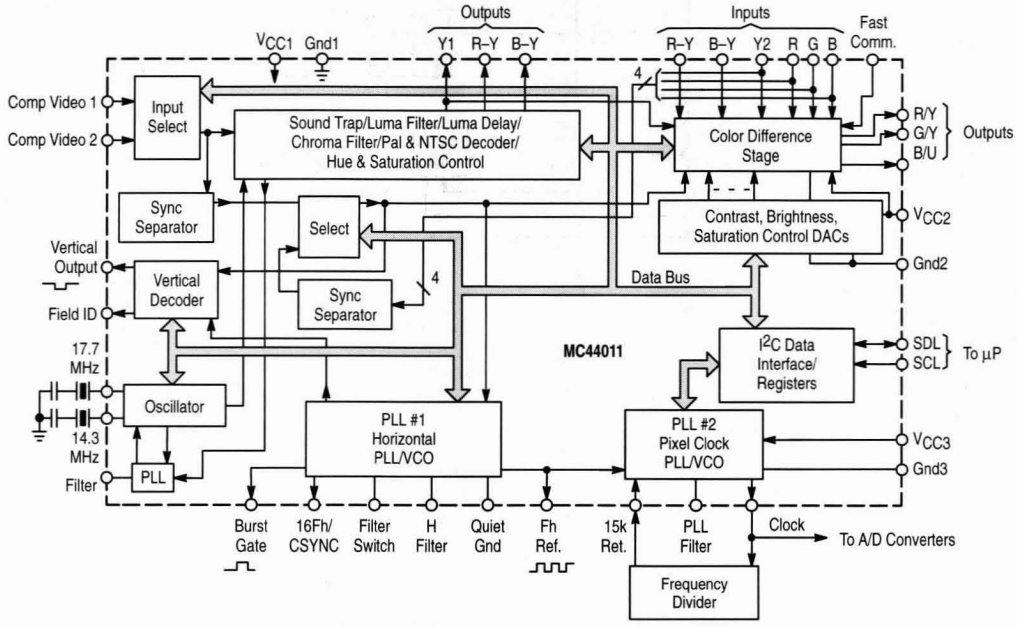
Case 777, 824E

The MC44011, a member of the MC44000 Chroma 4 family, is designed to provide RGB or YUV outputs from a variety of inputs. The inputs may be either PAL or NTSC composite video (two inputs), S–VHS, RGB, and color difference (R–Y, B–Y).

The MC44011 provides a sampling clock output for use by a subsequent analog to digital converter. The sampling clock (6.0 to 40 MHz) is phase–locked to the horizontal frequency. Additional outputs include composite sync, vertical sync, field identification, luminance, burst gate, and horizontal frequency.

Control of the MC44011, and reading of status flags is accomplished via an $I^2C$ bus.

- Multistandard Decoder, Accepts NTSC and PAL Composite Video
- Dual Composite Video or S–VHS Inputs
- All Chroma and Luma Channel Filtering, and Luma Delay Line are Integrated Using Sampled Data Filters Requiring no External components
- Digitally Controlled via $I^2C$ Bus
- Auxiliary Y, R–Y, B–Y Inputs
- Switched RGB Inputs with Separate Saturation Control
- Line–Locked Sampling Clock for Digitizing Video Signals
- Burst Gate Pulse Output for External Clamping
- Vertical Sync and Field Ident Outputs
- Software Selectable YUV or RGB Outputs Able to Drive A/D Converters



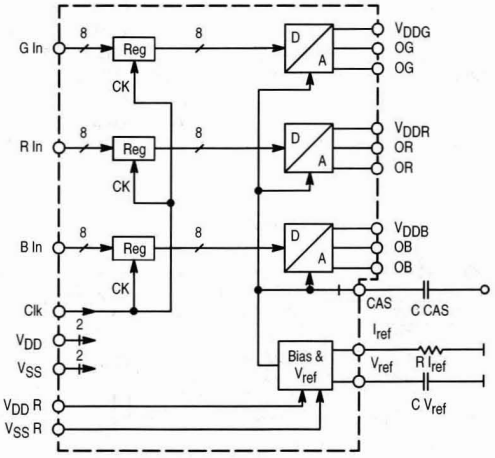
## Triple 8–Bit D/A Converter

**MC44200FB**

Case 824A

The MC44200 is a monolithic digital to analog converter for three independent channels fabricated in CMOS technology. The part is specifically designed for video applications. Differential outputs are provided, allowing for a large output voltage range.

- 8–Bit Resolution
- Differential Outputs
- 55 msps Conversion Speed
- Large Output Voltage Range
- Low Current Mode
- Single 5.0 V Power Supply
- TTL Compatible Inputs
- Integrated Reference Voltage



# Triple 8–Bit A/D Converter

**MC44251FN**

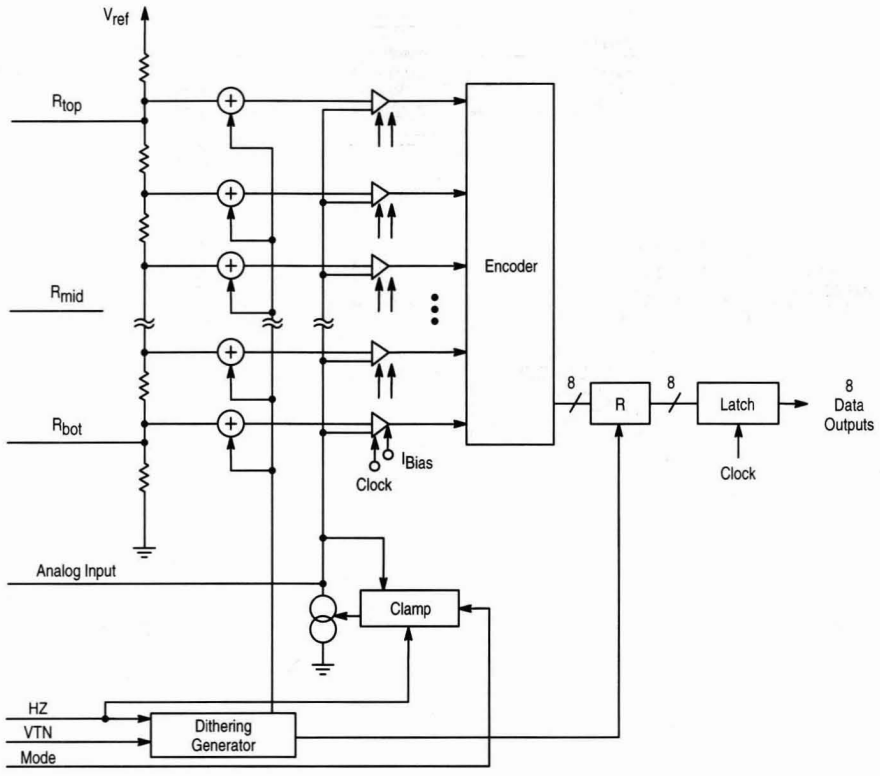
Case 777

The MC44251 contains three independent parallel analog to digital converters. Each ADC consists of 256 latching comparators and an encoder. Input clamps allow for AC coupling of the input signals, and dc coupling is also allowed. For video processing performance enhancements, a dither generator with subsequent digital correction is provided to each ADC. The outputs of the MC44251 can be set to a high impedance state.

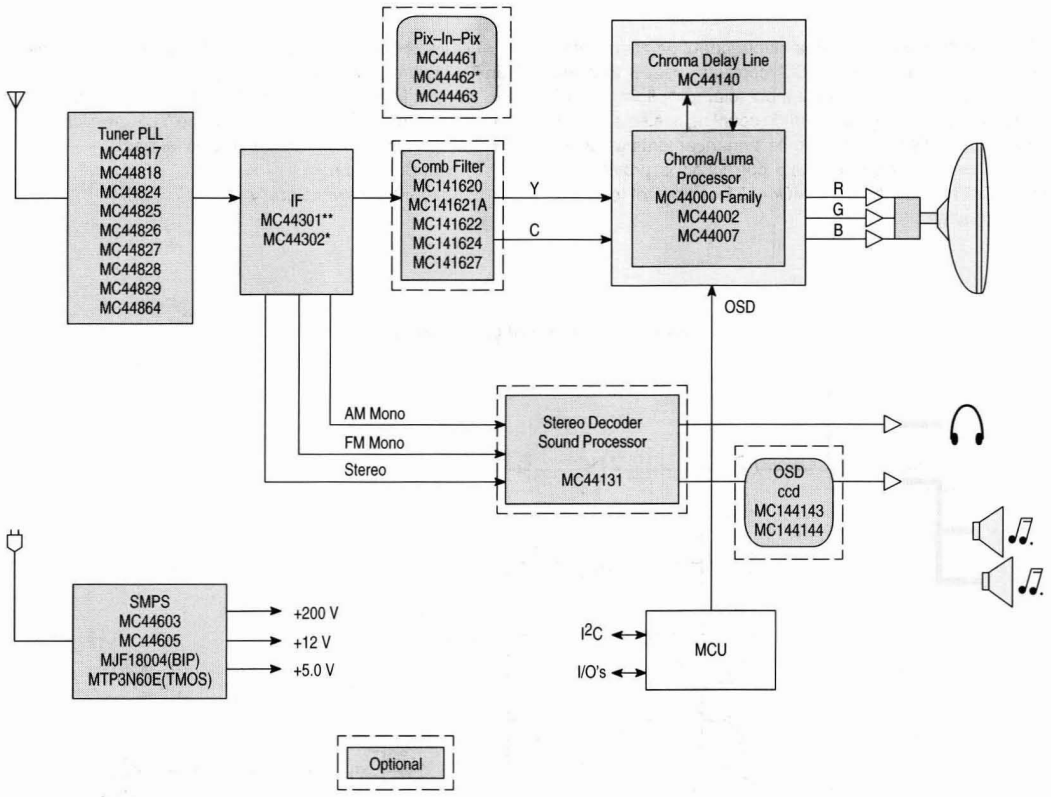
These A/Ds are especially suitable as front end converters in TV picture processing.

- 18 MHz Maximum Conversion Speed (MC44251)
- Input Clamps Suitable for RGB and YUV Applications
- Built–in Dither Generator with Subsequent Digital Correction
- Single 5.0 V Power Supply

**Simplified Diagram of One of the ADCs**



**Color TV Block Diagram**




* In Development
** Not recommended for new designs.

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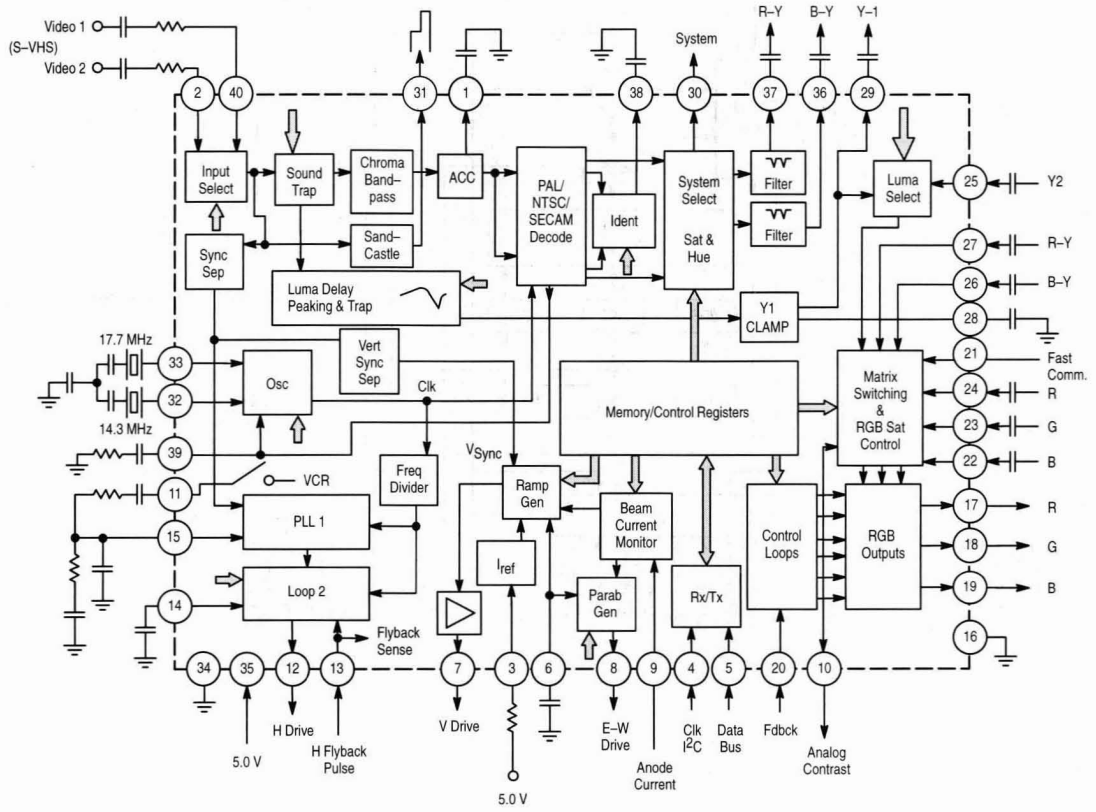
# Multistandard Video/Timebase Processor

**MC44002P, MC44007P**

Case 711

The MC44002/7 is a highly advanced circuit which performs most of the basic functions required for a color TV. All of its advanced features are under processor control via an I2C bus, enabling potentiometer controls to be removed completely. In this way the component count may be reduced dramatically to allow significant cost savings and the possibility of implementing sophisticated automatic test routines. Using the MC44002/7, TV manufacturers will be able to build a standard chassis for anywhere in the world.

- Operation from a Single 5.0 V Supply; Typical Current Consumption Only 120 mA
- Full PAL/SECAM/NTSC Capability (MC44002 Only)
- MC44007 Decodes PAL/NTSC Only
- Dual Composite Video or S–VHS Inputs
- All Chroma/Luma Channel Filtering, and Luma Delay Line are Integrated Using Sampled Data Filters Requiring No External Components
- Filters Automatically Commutate with Change of Standard
- Chroma Delay Line is Realized with Companion Device (MC44140)
- RGB Drives Incorporate Contrast and Brightness Controls and Auto Gray Scale
- Switched RGB Inputs with Saturation Control
- Auxiliary Y, R–Y, B–Y Inputs
- Line Timebase Featuring H–Phase Control and Switchable Phase Detector Gain and Time Constant
- Vertical Timebase Incorporating the Vertical Geometry Corrections
- E–W Parabola Drive Incorporating the Horizontal Geometry Corrections
- Beam Current Monitor with Breathing Compensation
- 16:9 Display Mode Capability

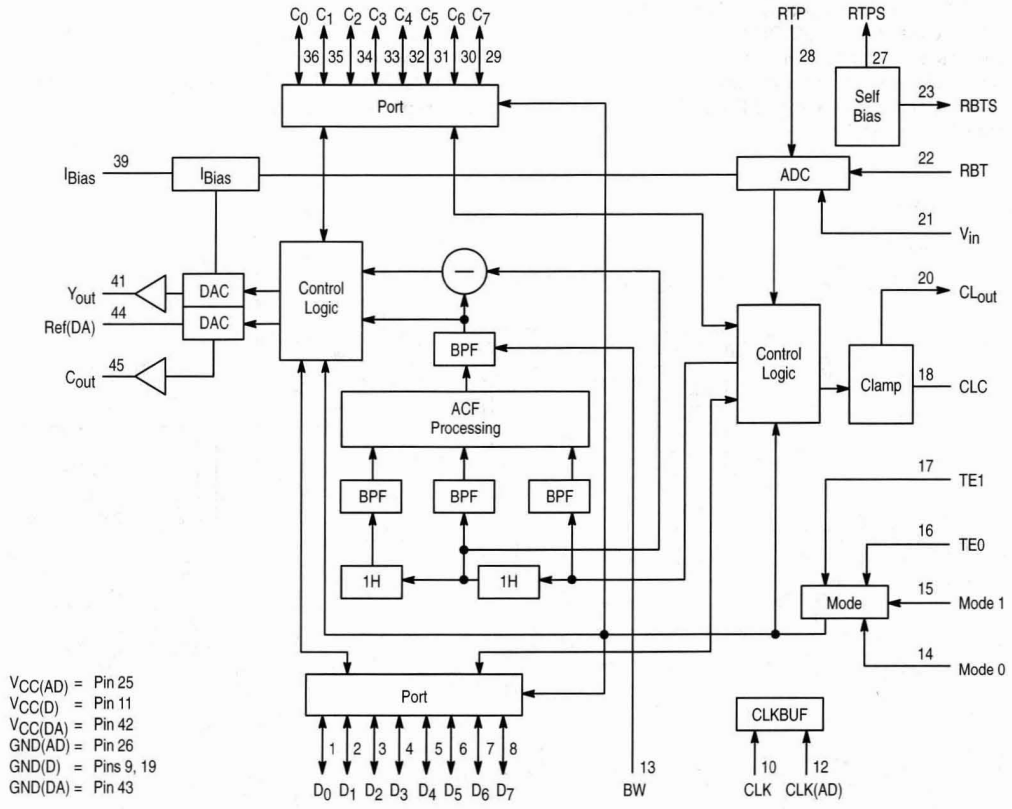


## Advanced NTSC Comb Filter

**MC141621FB**
Case 898

The MC141621 is an advanced NTSC comb filter for VCR and TV applications. It separates the luminance (Y) and chrominance (C) signals from the NTSC composite video signal by using digital signal processing techniques. This filter allows a video signal input of an extended frequency bandwidth by using a 4.0 $F_{SC}$ clock. In addition, the filter minimizes dot crawl and cross color effects. The built–in A/D and D/A converters allow easy connections to analog video circuits.

- Built–in High Speed 8–Bit A/D Converter
- Two Line Memories (1820 Bytes)
- Advanced Combing Process
- Two 8–Bit D/A Converters
- Built–in Clamp Circuit
- On–Chip Reference Voltage Regulator for ADC
- Digital Interface Mode



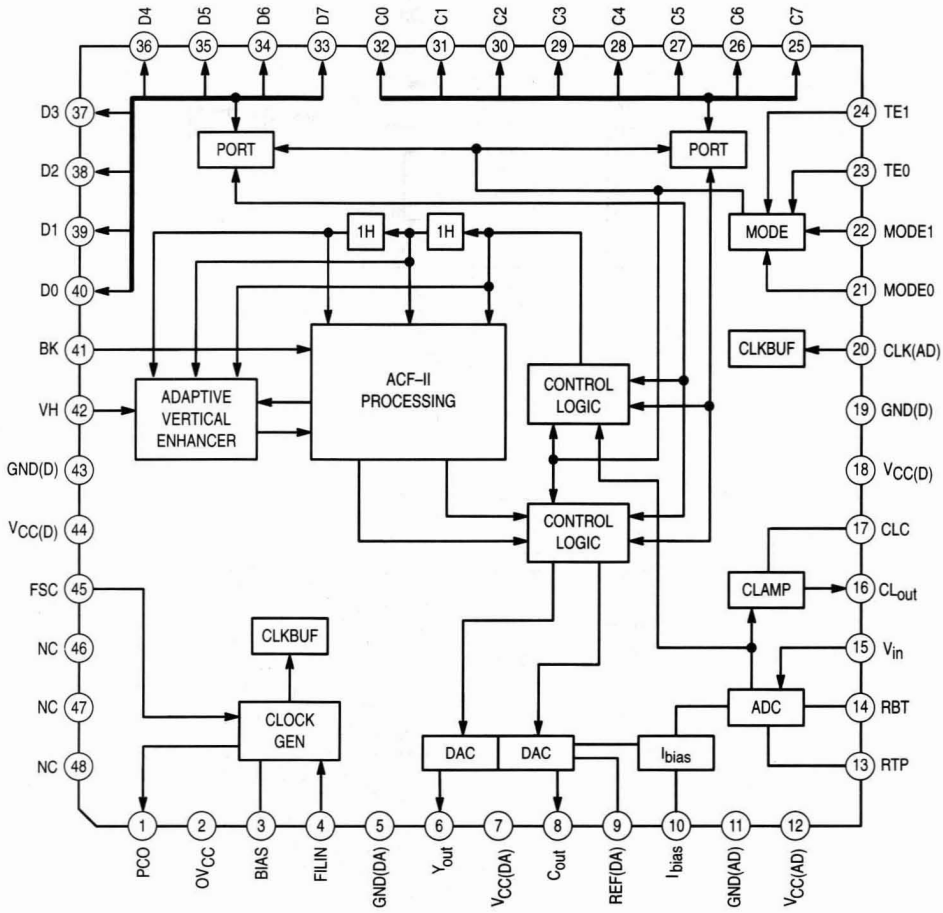
# Advanced Comb Filter–II (ACF–II)

**MC141622AFU**

Case 898

The Advanced Comb Filter–II is a video signal processor for VCRs and TVs. It's function is to separate the Luminance Y and Chrominance C signals from the NTSC composite video signal. The ACF–II minimizes dot–crawl and cross–color. A built–in PLL provides a 4xfsc clock from either an NTSC subcarrier signal or a 4xfsc input. This allows a video signal input of an extended frequency bandwidth. The built–in vertical enhancer circuit improves the quality of the Luminance Y signal. The built–in A/D and D/A converters allow easy connection to analog video circuits.

- Built–in High Speed 8–Bit A/D Converter
- Two Line Memories (1820 Bytes)
- Advanced Comb–II Process
- Vertical Enhancer Circuit
- Two High Speed 8–Bit D/A Converters
- 4xfsc PLL Circuit
- Built–in Clamp Circuit
- Digital Interface Mode
- On–Chip Reference Voltage Regulator for A/D Converter



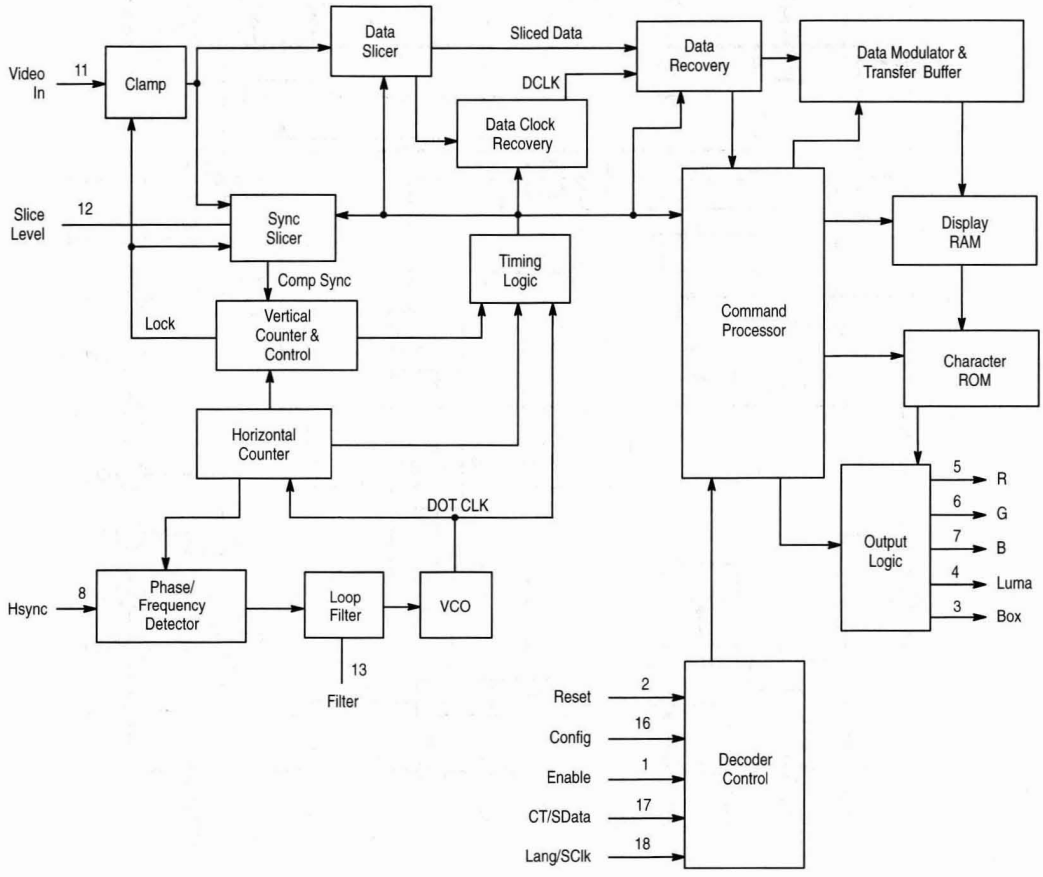

9

## Closed–Caption Decoder

**MC144143P**
Case 707

The MC144143 is a Line 21 closed–caption decoder for use in television receivers or set top decoders conforming to the NTSC broadcast standard. Capability for processing and displaying all of the latest standard Line 21 closed–caption format transmissions is included. The device requires a closed–caption encoded composite video signal, a horizontal sync signal, and an external keyer to produce captioned video. RGB outputs are provided, along with a luminance and a box signal, allowing simple interface to both color and black and white receivers.

- Conforms to the FCC Report and Order as Amended by the Petition for Reconsideration on Gen. Doc. 91–1
- Supports Four Different Data Channels, Time Multiplexed within the Line 21 Data Stream: Captions Utilizing Languages 1 & 2, Plus Text Utilizing Languages 1 & 2
- Output Logic Provides Hardware Underline Control and Italics Slant Generation
- Single Supply Operating Voltage Range: 4.75 to 5.25 V
- Composite Video Input Range: 0.7 to 1.4 $V_{pp}$
- Horizontal Sync Input Polarity can be either Positive or Negative
- Internal Timing/Sync Signals Derived from On–Chip VCO



## Enhanced Closed–Caption Decoder

**MC144144P**
Case 707

The MC144144 is a Line 21 closed–caption decoder for use in television receivers or set–top decoders conforming to the NTSC standard. Capability for processing and displaying all of the latest standard Line 21 closed–caption format transmissions is included. The device requires a closed–caption encoded composite video signal, a horizontal sync signal, and an external keyer to produce captioned video. RGB and box signal outputs are provided, which along with the mode select, allow simple interfacing to either color or black–and–white TV receivers.

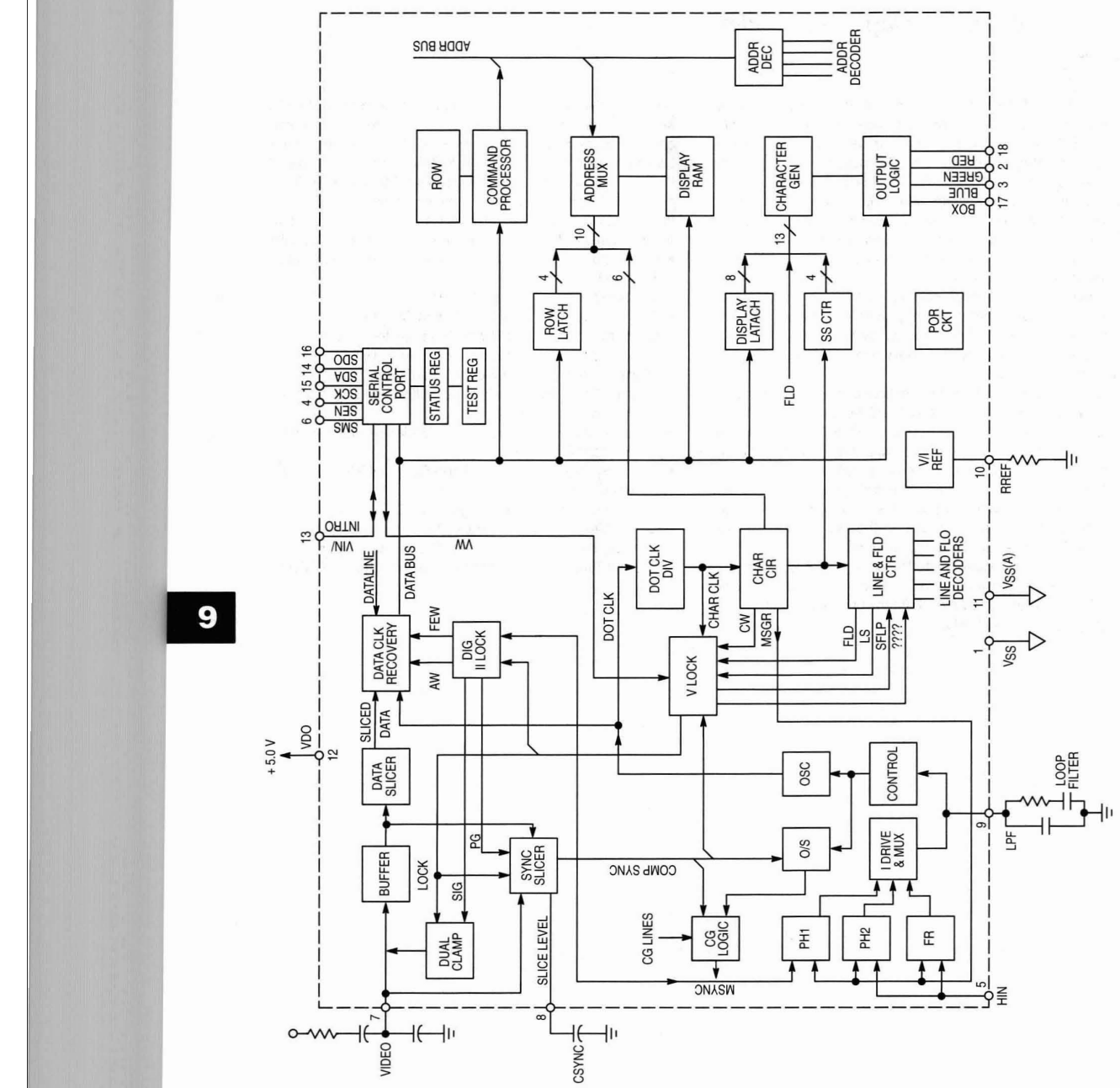
Display storage is accomplished with an on–chip RAM. A modified ASCII character set, which includes several non–English characters, is decoded by an on–chip ROM. An on–screen character appears as a white or colored dot matrix on a black background.

Captions (video–related information) can be up to four rows appearing anywhere on the screen and can be displayed in two modes: roll–up, paint–on, or pop–on. With rollup captions, the row scrolls up and new information appears at the bottom row each time a carriage return is received. Pop–on captions work with two memories. One memory is displayed while the other is used to accumulate new data. A special command causes the information to be exchanged in the two memories, thus causing the entire caption to appear at once.

When text (non–video related information) is displayed, the rows contain a maximum of 32 characters over a black box which overwrites the screen. Fifteen rows of characters are displayed in the text mode.

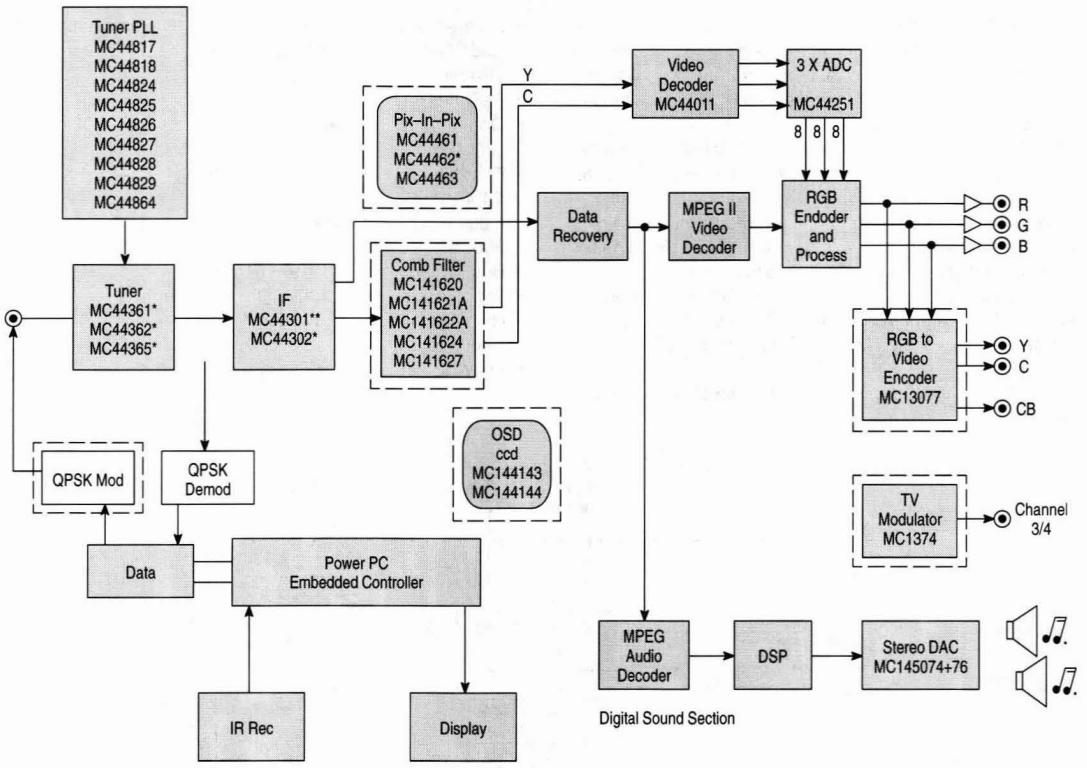
An on–chip processor controls the manipulation of data for storage and display. Also controlled are the loading, addressing, and clearing of the display RAM. The processor transfers the data received to the RAM during scan lines 21 through 42. The operation of the display RAM, character ROM, and output logic circuits are controlled during scan lines 43 through 237. The functions of the MC144144 are controlled via a serial port which may be configured to be either $I^2C$ or SPI.

- Conforms to FCC Report and Order as Amended by the Petition for Reconsideration on Gen. Doc. 91–1
- Conforms to EIA–608 for XDS Data Structure
- Supports Four Different Data Channels for Field 1 and Five Different Data Channels for Field 2, Time Multiplexed within the Line 21 Data Stream: Captions Utilizing Languages 1 and 2, Text Utilizing Languages 1 and 2 and XDS Support
- Output Logic Provides Hardware Underline Control and Italics Slant Generation
- Single Supply, Operating Voltage Range: 4.75 to 5.25 V
- Supply Current: 20 mA (Preliminary)
- Operating Temperature Range: 0 to 70°C
- Composite Video Input Range: 0.7 to 1.4 $V_{pp}$
- Horizontal Input Polarity: Either Positive or Negative
- Internal Timing and Sync Signals Derived from On–Chip VCO


ADDR BUS
ADDR DEC
ADDR DECODER
ROW
COMMAND PROCESSOR
ADDRESS MUX
DISPLAY RAM
CHARACTER GEN
OUTPUT LOGIC
BOX
BLUE
GREEN
RED
ROW LATCH
DISPLAY LATACH
SS CTR
POR CKT
FLD
SERIAL CONTROL PORT
SDO
SDA
SCK
SEN
SMS
STATUS REG
TEST REG
V/I REF
RREF
INTRO
VIN/
VW
DATALINE
DATA BUS
DOT CLK DIV
CHAR CLK
CHAR CIR
LINE & FLD CTR
LINE AND FLD DECODERS
DOT CLK
CW
MSGR
FLD
LS
SFLP
????
VSS(A)
VSS
DATA CLK RECOVERY
FEW
AW
DIG II LOCK
V LOCK
SLICED DATA
+5.0 V
VDO
DATA SLICER
OSC
CONTROL
LOOP FILTER
LPF
BUFFER
LOCK
SIG
PG
SYNC SLICER
COMP SYNC
O/S
I DRIVE & MUX
DUAL CLAMP
SLICE LEVEL
CG LINES
CG LOGIC
PH1
PH2
FR
MSYNC
HIN
VIDEO
CSYNC

## Video Circuits (continued)

**Set–Top Block Diagram**




* In Development
** Not recommended for new designs.

9

# PLL Tuning Circuits with 3–Wire Bus

**MC44817BD, D**

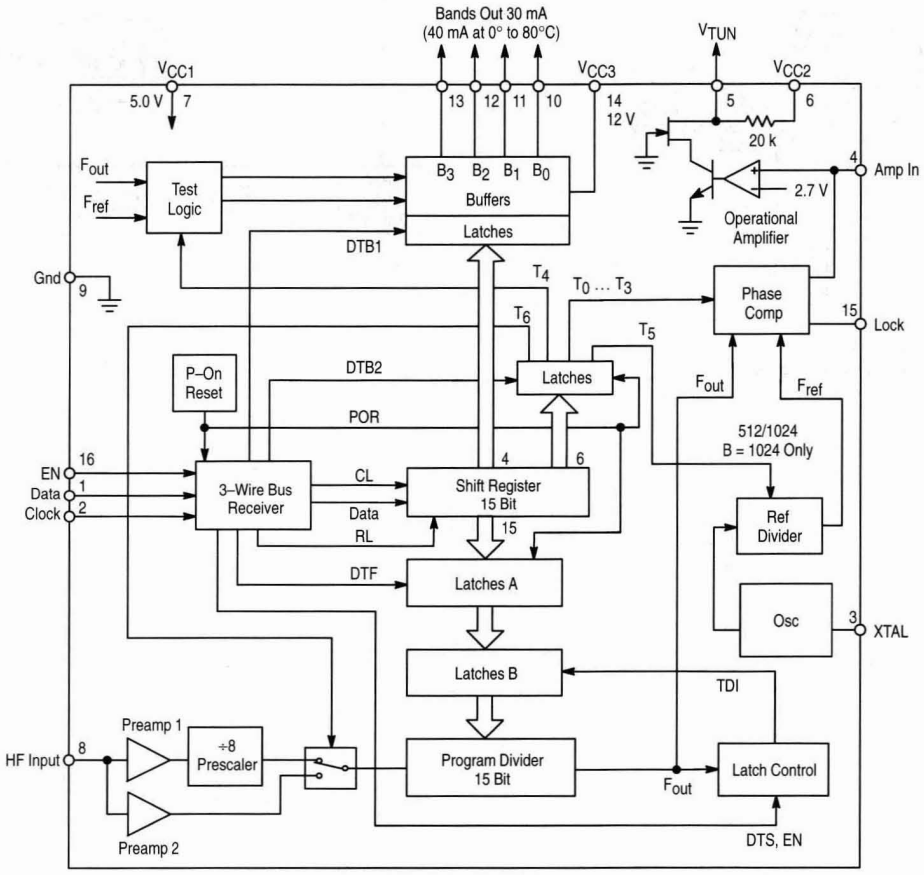
Case 751B

The MC44817/17B are tuning circuits for TV and VCR tuner applications. They contain on one chip all the functions required for PLL control of a VCO. The integrated circuits also contain a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44817 has programmable 512/1024 reference dividers while the MC44817B has a fixed reference divider of 1024.

The MC44817/17B are manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (3–Wire Bus). Data and Clock Inputs are IIC Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider Accepts Input Frequencies up to 165 MHz
- Reference Divider: Programmable for Division Ratios 512 and 1024. The MC44817B has a Fixed 1024 Reference Divider
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Integrated PNP Band Buffers for 40 mA ($V_{CC1}$ to 14.4 V)
- Output Options for the Reference Frequency and the Programmable Divider
- Bus Protocol for 18 or 19 Bit Transmission
- Extra Protocol for 34 Bit for Test and Further Features
- High Sensitivity Preamplifier
- Circuit to Detect Phase Lock
- Fully ESD Protected



# PLL Tuning Circuit with I²C Bus

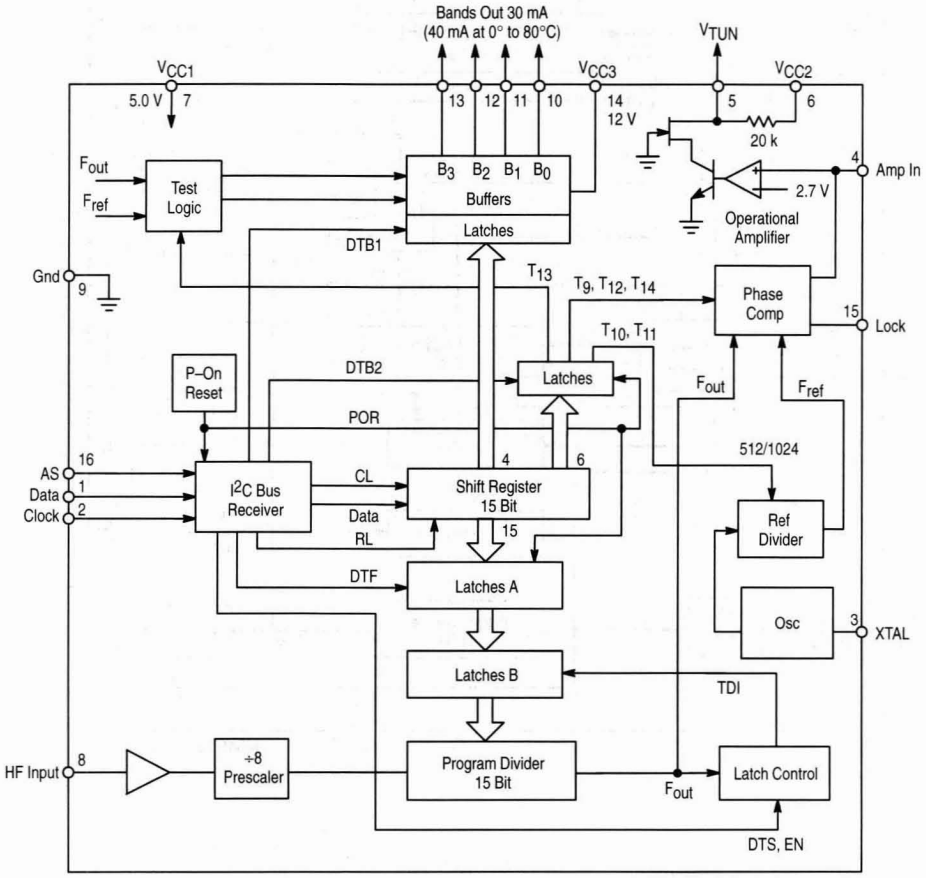
**MC44818D**

Case 751B

The MC44818 is a tuning circuit for TV and VCR tuner applications. It contains, on one chip, all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz. The MC44818 is a pin compatible drop–in replacement for the MC44817, where the only difference is the MC44818 has a fixed divide–by–8 prescaler (cannot be bypassed) and the MC44817 uses the three wire bus.

The MC44818 has programmable 512/1024 reference dividers and is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I²C Bus). Data and Clock Inputs are 3–Wire Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider Accepts Input Frequencies up to 165 MHz
- Reference Divider: Programmable for Division Ratios 512 and 1024.
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Integrated PNP Band Buffers for 40 mA ($V_{CC1}$ to 14.4 V)
- Output Options for the Reference Frequency and the Programmable Divider
- High Sensitivity Preamplifier
- Circuit to Detect Phase Lock
- Fully ESD Protected



# PLL Tuning Circuits with I²C Bus

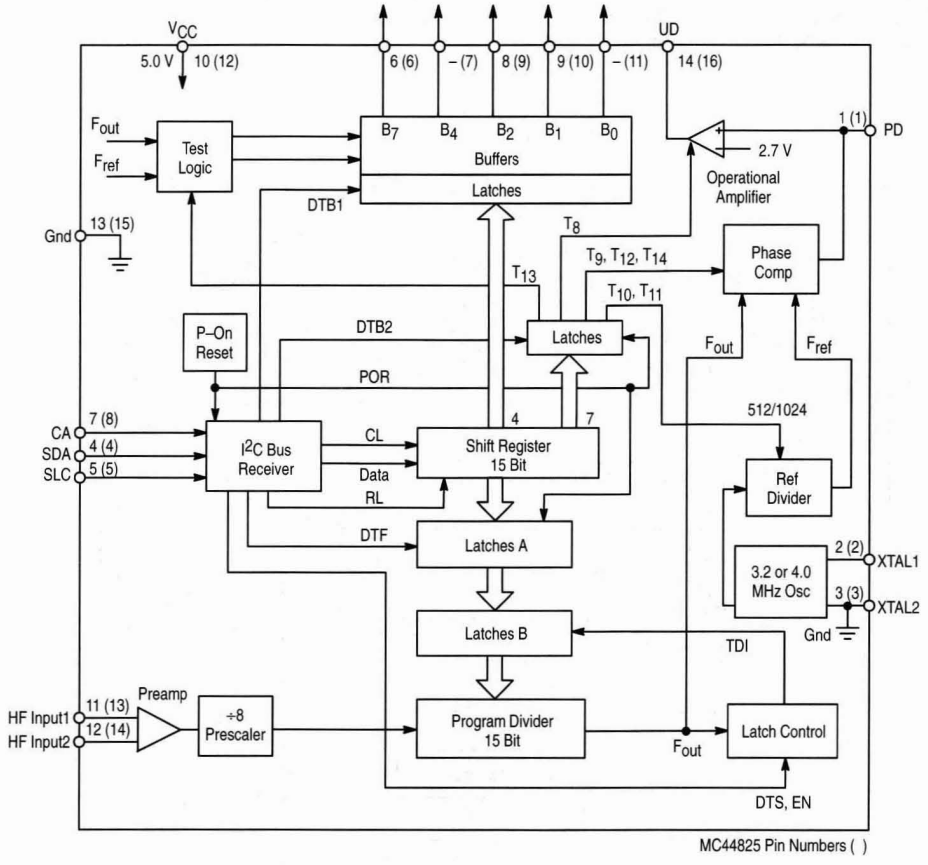
**MC44824/25D**

Case 751A, 751B

The MC44824/25 are tuning circuits for TV and VCR tuner applications. They contain on one chip all the functions required for PLL control of a VCO. The integrated circuits also contain a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44824/25 are manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I²C Bus). Data and Clock Inputs are 3–Wire Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider
- Reference Divider: Programmable for Division Ratios 512 and 1024
- 3–State Phase/Frequency Comparator
- 4 Programmable Chip Addresses
- 3 Output Buffers (MC44824) respectively; 5 Output Buffers (MC44825) for 10 mA/15 V
- Operational Amplifier for use with External NPN Transistor
- SO–14 Package for MC44824 and SO–16 for MC44825
- High Sensitivity Preamplifier
- Fully ESD Protected



## PLL Tuning Circuit with 3–Wire Bus

**MC44827DTB**

Case 948F

The MC44827 is a tuning circuit for TV and VCR tuner applications. This device contains on one chip all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44827 is controlled by a 3–wire bus. It has the same function as the MC44828 which is $I^2C$ bus controlled. The MC44827 and MC44828 can replace each other to allow conversion between 3–wire bus and $I^2C$ bus control.

The MC44827 is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

The MC44827 has the same features as MC44817 with the following differences:

- Lower Power Consumption, 200 mW Typical
- Improved Prescaler with Higher Margins for Sensitivity and Temperature Range. (A typical device is functional in a temperature range greater than –40 to 100°C.)
- Lock Detector with Push–Pull Output
- No Bypass of Divide–by–8 Prescaler
- TSSOP Package

## PLL Tuning Circuit with $I^2C$ Bus

**MC44828DTB**

Case 948F

The MC44828 is a tuning circuit for TV and VCR tuner applications. This device contains on one chip all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44828 is controlled by an $I^2C$ bus. It has the same function as the MC44827 which is 3–wire bus controlled. The MC44827 and MC44828 can replace each other to allow conversion between 3–wire bus and $I^2C$ bus control.

The MC44828 is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

The MC44828 has the same features as MC44818 with the following differences:

- Lower Power Consumption, 200 mW Typical
- Improved Prescaler with Higher Margins for Sensitivity and Temperature Range. (A typical device is functional in a temperature range greater than –40 to 100°C.)
- Lock Detector with Push–Pull Output
- TSSOP Package

# PLL Tuning Circuit with I²C Bus

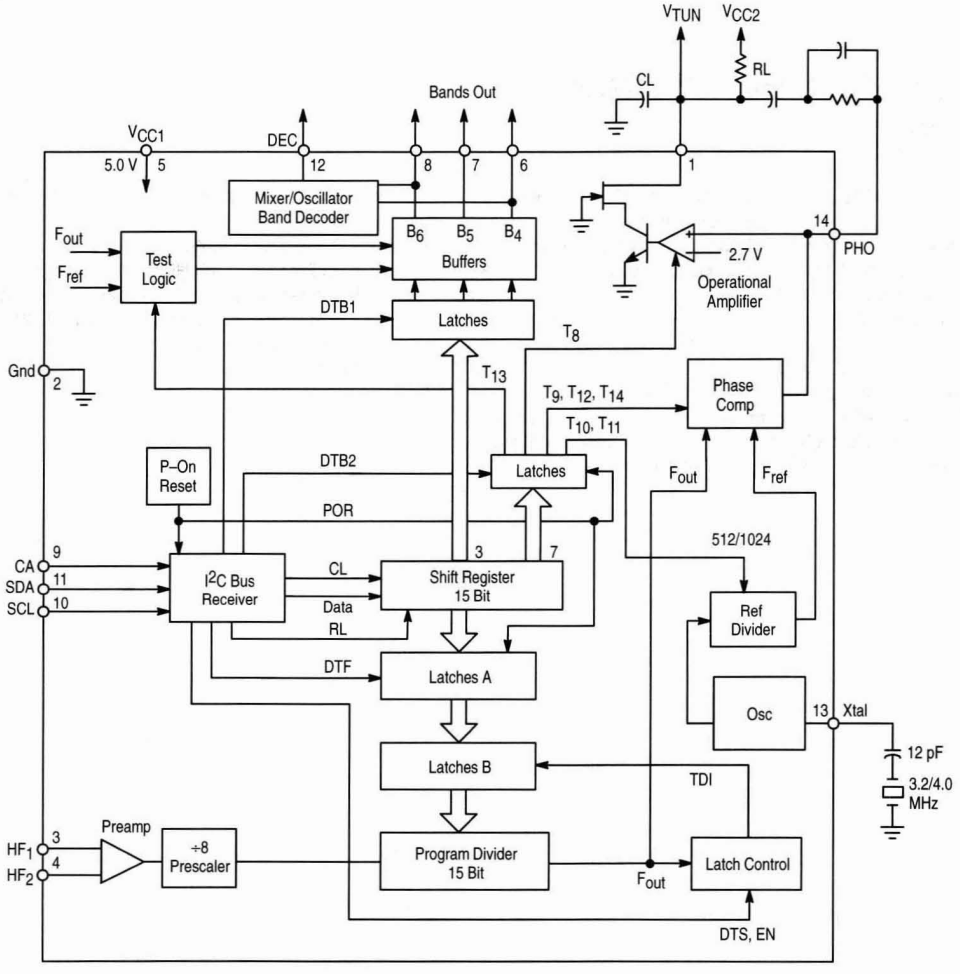
**MC44829D**

Case 751A

The MC44829 is a tuning circuit for TV and VCR tuner applications. It contains, on one chip, all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz. The circuit has a band decoder that provides the band switching signal for the mixer/oscillator circuit. The decoder is controlled by the buffer bits.

The MC44829 has programmable 512/1024 reference dividers and is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I²C Bus)
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider
- Reference Divider: Programmable for Division Ratios 512 and 1024
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Programmable Chip Addresses
- Integrated Band Decoder for the Mixer/Oscillator Circuit
- Band Buffers with Low "On" Voltage (0.4 V Maximum at 5.0 mA)
- Fully ESD Protected to MIL–STD–883C, Method 3015.7 (2000 V, 1.5 kΩ, 150 pF)



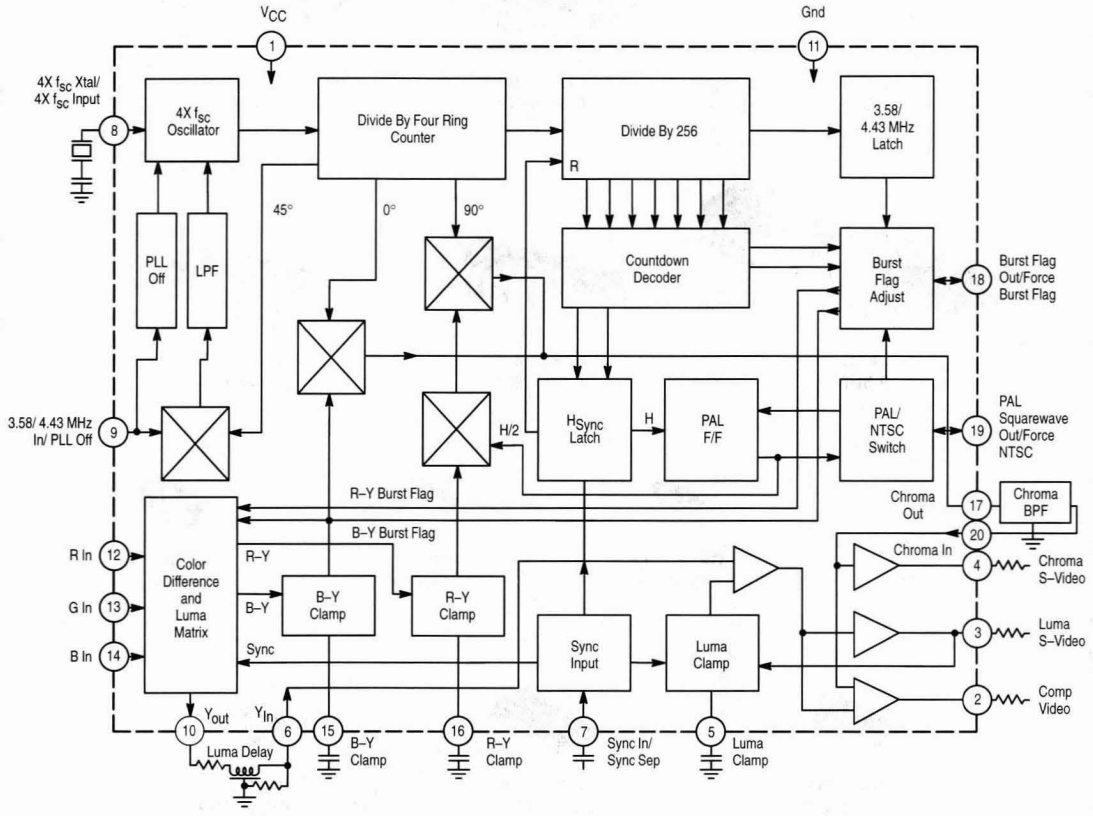
# Advanced PAL/NTSC Encoder

**MC13077P, DW**

Case 738, 751D

The MC13077 is an economical, high quality, RGB encoder for PAL or NTSC applications. It accepts red, green, blue and composite sync inputs and delivers either composite PAL or NTSC video, and S–Video Chroma and Luma outputs. The MC13077 is manufactured using Motorola's high density, bipolar MOSAIC® process.

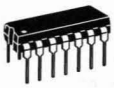
- Single 5.0 V Supply
- Composite Output
- S–Video Outputs
- PAL/NTSC Switchable
- PAL Squarewave Output
- PAL Sequence Resettable
- Internal/External Burst Flag
- Modulator Angles Accurate to 90°
- Burst Position/Duration Determined Digitally
- Subcarrier Reference from a Crystal or External Source




9

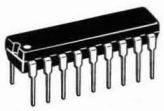
# Consumer Electronic Circuits Package Overview

CASE 626
P SUFFIX

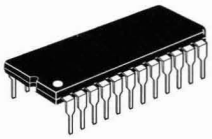


CASE 646
P SUFFIX

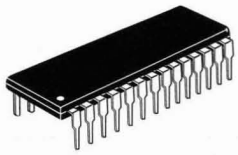
CASE 648
P SUFFIX



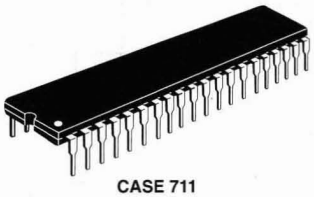
CASE 707
P SUFFIX



CASE 709
P SUFFIX

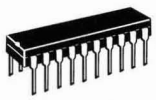


CASE 710
P SUFFIX



CASE 711
P SUFFIX

CASE 724
P SUFFIX



CASE 738
H, P SUFFIX

CASE 751
D SUFFIX

CASE 751A
D SUFFIX

CASE 751B
D SUFFIX

CASE 751D
DW SUFFIX

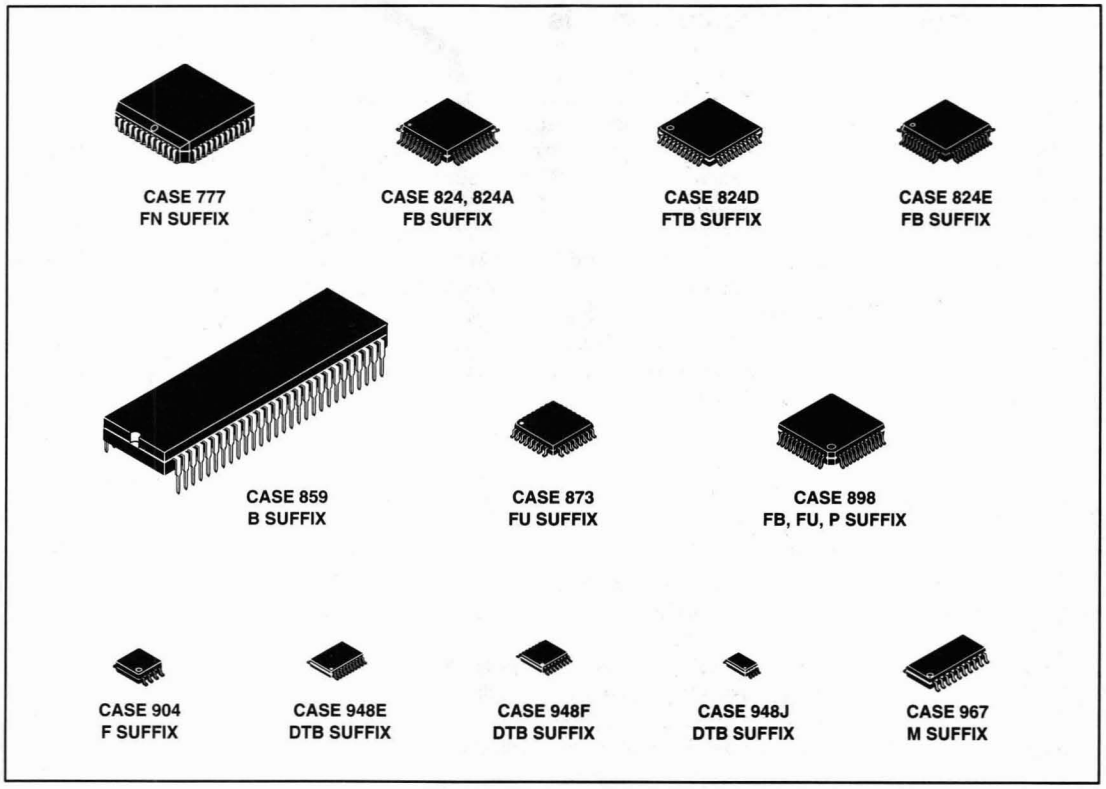
CASE 751E
DW SUFFIX

CASE 751F
DW SUFFIX

CASE 751G
DW SUFFIX

9

## Consumer Electronic Circuits Package Overview (continued)



CASE 777
FN SUFFIX

CASE 824, 824A
FB SUFFIX

CASE 824D
FTB SUFFIX

CASE 824E
FB SUFFIX

CASE 859
B SUFFIX

CASE 873
FU SUFFIX

CASE 898
FB, FU, P SUFFIX

CASE 904
F SUFFIX

CASE 948E
DTB SUFFIX

CASE 948F
DTB SUFFIX

CASE 948J
DTB SUFFIX

CASE 967
M SUFFIX

9

# Device Listing and Related Literature

## Entertainment Radio Receiver Circuits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| MC13020 | Motorola C-QUAM AM Stereo Decoder | 9–76 |
| MC13022 | Advanced Medium Voltage AM Stereo Decoder | 9–81 |
| MC13022A | Advanced Medium Voltage AM Stereo Decoder | 9–86 |
| MC13025 | Electronically Tuned Radio Front End | 9–91 |
| MC13027, MC13122 | AMAX Stereo Chipset | 9–94 |
| MC13028A | Advanced Wide Voltage IF and C–QUAM AM Stereo Decoder | 9–119 |
| MC13029A | Advanced Medium Voltage IF and C–QUAM AM Stereo Decoder with FM Amplifier and AM/FM Internal Switch | 9–137 |
| MC13030 | Dual Conversion AM Receiver | 9–156 |
| MC13060 | Mini-Watt Audio Output | 9–171 |
| MC34119 | Low Power Audio Amplifier | 9–227 |


## Video Circuits


| Device | Function | Page |
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| MC1374 | TV Modulator Circuit | 9–34 |
| MC1377 | Color Television RGB to PAL/NTSC Encoder | 9–42 |
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| MC1391 | TV Horizontal Processor | 9–62 |
| MC3346 | General Purpose Transistor Array One Differentially Connected Pair and Three Isolated Transistor Arrays | 9–69 |
| MC13077 | Advanced PAL/NTSC Encoder | 9–175 |
| MC13081X | Multimode Color Monitor Horizontal, Vertical, and Video Combination Processor | 9–187 |
| MC13280AY, MC13281A/B | 80/100 MHz Video Processor | 9–205 |
| MC13282A | 100 MHz Video Processor with OSD Interface | 9–215 |
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| MC44002, MC44007 | Chroma 4 Multistandard Video Processor | 9–236 |
| MC44011 | Bus Controlled Multistandard Video Processor | 9–275 |
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| MC44144 | Subcarrier Phase–Locked Loop | 9–326 |
| MC44145 | Pixel Clock Generator/Sync Separator | 9–331 |
| MC44353, MC44354, MC44355 | PLL Tuned UHF Audio/Video Modulator ICs for PAL, SECAM and NTSC TV Systems | 9–338 |
| MC44461 | Picture–in–Picture (PIP) Controller | 9–341 |
| MC44462 | Y–C Picture–in–Picture (PIP) Controller | 9–354 |
| MC44463 | Replay and Multiple Picture–in–Picture (PIP) Controller | 9–360 |

## Video Circuits (continued)


| Device | Function | Page |
|---|---|---|
| **MC44817, MC44817B** | PLL Tuning Circuits with 3–Wire Bus | 9–367 |
| **MC44818** | PLL Tuning Circuit with I²C Bus | 9–374 |
| **MC44824, MC44825** | PLL Tuning Circuits with I²C Bus | 9–381 |
| **MC44826** | PLL Tuning Circuit with I²C Bus | 9–388 |
| **MC44827** | PLL Tuning Circuit with 3–Wire Bus | 9–395 |
| **MC44828** | PLL Tuning Circuit with I²C Bus | 9–396 |
| **MC44829** | PLL Tuning Circuit with I²C Bus | 9–397 |
| **MC44864** | PLL Tuning Circuit with 1.3 GHz Prescaler and D/A Converters for Automatic Tuner Alignment | 9–405 |


## Remote Control Circuit


| Device | Function | Page |
|---|---|---|
| **MC3373*** | Remote Control Amplifier/Detector | 9–72 |


## RELATED APPLICATION NOTES

| App Note | Title | Related Device |
|---|---|---|
| AN545A | Television IF Amplifiers | **MC1350** |
| AN829 | Application of the MC1374 TV Modulator | **MC1374** |
| AN921 | Horizontal APC/AFC Loops | **MC1391** |
| AN932 | Application of the MC1377 Color Encoder | **MC1377** |
| AN1044 | A Monolithic Composite Video Synchronizer | **MC1378** |
| AN1548 | Guidelines for Debugging the MC44011 Video Decoder | **MC44011** |

**NOTE:** * Not recommended for new designs.

9

MOTOROLA

# CA3146

# General Purpose Transistor Array

## One Differentially Connected Pair and Three Isolated Transistor Arrays

The CA3146 is designed for general purpose, low power applications in the dc through VHF range.

- Guaranteed Base–Emitter Voltage Matching
- Operating Current Range Specified: 10 μA to 10 mA
- Five General Purpose Transistors in One Package

**GENERAL PURPOSE TRANSISTOR ARRAY**

**SEMICONDUCTOR TECHNICAL DATA**

**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

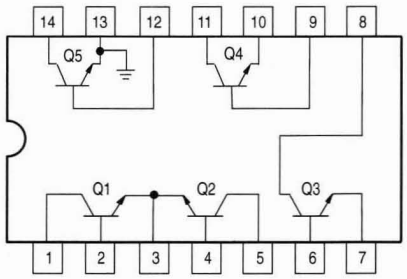
**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector–Emitter Voltage | $V_{CEO}$ | 130 | Vdc |
| Collector–Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Collector–Substrate Voltage | $V_{CIO}$ | 20 | Vdc |
| Emitter–Base Voltage | $V_{EBO}$ | 5.0 | Vdc |
| Collector Current | $I_C$ | 50 | mAdc |
| Operating Temperature Range | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| CA3146D | $T_A$ = – 40° to +85°C | SO–14 |

**PIN CONNECTIONS**




Pin 13 is connected to substrate and must remain at the lowest circuit potential.

## ELECTRICAL CHARACTERISTICS

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **STATIC CHARACTERISTICS** | | | | | |
| Collector–Base Breakdown Voltage ($I_C$ = 10 μAdc) | $V_{(BR)CBO}$ | 40 | 89 | – | Vdc |
| Collector–Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc) | $V_{(BR)CEO}$ | 35 | 45 | – | Vdc |
| Collector–Substrate Breakdown Voltage ($I_{CI}$ = 10 μA) | $V_{(BR)CIO}$ | 40 | 85 | – | Vdc |
| Emitter–Base Breakdown Voltage ($I_E$ = 10 μA) | $V_{(BR)EBO}$ | 5.0 | – | – | Vdc |
| Collector–Base Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.68 | 40 | nAdc |
| DC Current Gain<br>($I_C$ = 10 mAdc, $V_{CE}$ = 5.0 Vdc)<br>($I_C$ = 1.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | <br>–<br>– | <br>171<br>188 | <br>–<br>– | – |
| Base–Emitter Voltage ($V_{CE}$ = 5.0 Vdc, $I_E$ = 1.0 mAdc) | $V_{BE}$ | – | 0.7 | – | Vdc |
| Collector–Emitter Saturation Voltage ($I_C$ = 10 mA, $I_B$ = 0.4 mA) | $V_{CE(sat)}$ | – | 0.28 | 0.5 | Vdc |
| Magnitude of Input Offset Current $\lvert I_{IO1} - I_{IO2} \rvert$ ($V_{CE}$ = 5.0 Vdc, $I_{C1} = I_{C2}$ = 1.0 mAdc) | $I_{IO}$ | – | 0.03 | 2.0 | μAdc |
| Magnitude of Input Offset Voltage $\lvert V_{BE1} = V_{BE2} \rvert$ ($V_{CE}$ = 5.0 Vdc, $I_E$ = 1.0 mAdc) | $\lvert V_{IO} \rvert$ | – | 0.13 | 2.0 | mVdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Low Frequency Noise Figure ($V_{CE}$ = 5.0 Vdc, $I_C$ = 100 μAdc, $R_S$ = 1.0 kΩ, f = 1.0 kHz) | NF | – | 3.25 | – | dB |
| Forward Current Transfer Ratio ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $h_{fe}$ | – | 201.5 | – | – |
| Short Circuit Input Impedance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $h_{ie}$ | – | 6.7 | – | kΩ |
| Open Circuit Output Impedance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $h_{oe}$ | – | 15.6 | – | μmho |
| Reverse Voltage Transfer Ratio ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $h_{re}$ | – | 3.5 | – | $X10^{-4}$ |
| Input Admittance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $Y_{ie}$ | – | 0.14 + j0.16 | – | mmho |
| Forward Transfer Admittance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $Y_{fe}$ | – | 34.6 – j0.63 | – | mmho |
| Reverse Transfer Admittance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $Y_{re}$ | – | 62.0 – j59.4 | – | μmho |
| Output Admittance ($V_{CE}$ = 5.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $Y_{oe}$ | – | 0.16 + j0.14 | – | mmho |
| Current–Gain – Bandwidth Product ($V_{CE}$ = 5.0 Vdc, $I_C$ = 3.0 mAdc) | $f_T$ | 300 | 500 | – | MHz |
| Emitter–Base Capacitance ($V_{EB}$ = 5.0 Vdc, $I_E$ = 0 mAdc) | $C_{EB}$ | – | 1.17 | – | pF |
| Collector–Base Capacitance ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0 mAdc) | $C_{CB}$ | – | 0.68 | – | pF |
| Collector–Substrate Capacitance ($V_{CS}$ = 5.0 Vdc, $I_C$ = 0 mAdc) | $C_{CI}$ | – | 1.92 | – | pF |

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MOTOROLA

# MC1350

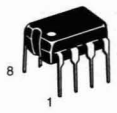
## Monolithic IF Amplifier

The MC1350 is an integrated circuit featuring wide range AGC for use as an IF amplifier in radio and TV over an operating temperature range of 0° to +75°C.

- Power Gain: 50 dB Typ at 45 MHZ
  50 dB Typ at 58 MHZ
- AGC Range: 60 dB Min, DC to 45 MHz
- Nearly Constant Input & Output Admittance over the Entire AGC Range
- $Y_{21}$ Constant ( –3.0 dB) to 90 MHz
- Low Reverse Transfer Admittance: < < 1.0 µmho Typ
- 12 V Operation, Single–Polarity Power Supply

**IF AMPLIFIER**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | V+ | +18 | Vdc |
| Output Supply Voltage | $V_1$, $V_8$ | +18 | Vdc |
| AGC Supply Voltage | $V_{AGC}$ | V+ | Vdc |
| Differential Input Voltage | $V_{in}$ | 5.0 | Vdc |
| Power Dissipation (Package Limitation)<br>Plastic Package<br>Derate above 25°C | $P_D$ | <br>625<br>5.0 | <br>mW<br>mW/°C |
| Operating Temperature Range | $T_A$ | 0 to +75 | °C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1350P | $T_A$ = 0° to +75°C | Plastic DIP |
| MC1350D | | SO–8 |

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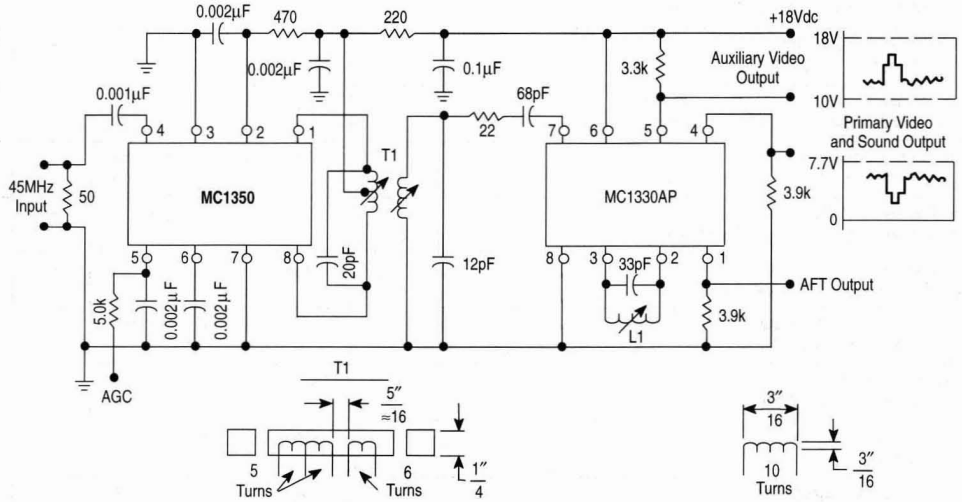
**Figure 1. Typical MC1350 Video IF Amplifier and MC1330 Low–Level Video Detector Circuit**




All windings #30 AWG tinned nylon acetate wire tuned with Carbonyl E or J slugs.

L1 wound with #26 AWG tinned nylon acetate wire tuned by distorting winding.

**ELECTRICAL CHARACTERISTICS** ($V^+$ = +12 Vdc, $T_A$ = +25°C, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| AGC Range, 45 MHz (5.0 V to 7.0 V) (Figure 1) | | 60 | 68 | – | dB |
| Power Gain (Pin 5 grounded via a 5.1 kΩ resistor) | $A_p$ | | | | dB |
| f = 58 MHz, BW = 4.5 MHz See Figure 6(a) | | – | 48 | – | |
| f = 45 MHz, BW = 4.5 MHz See Figure 6(a), (b) | | 46 | 50 | – | |
| f = 10.7 MHz, BW = 350 kHz See Figure 7 | | – | 58 | – | |
| f = 455 kHz, BW = 20 kHz | | – | 62 | – | |
| Maximum Differential Voltage Swing | $V_O$ | | | | $V_{pp}$ |
| 0 dB AGC | | – | 20 | – | |
| –30 dB AGC | | – | 8.0 | – | |
| Output Stage Current (Pins 1 and 8) | $I_1 + I_8$ | – | 5.6 | – | mA |
| Total Supply Current (Pins 1, 2 and 8) | $I_S$ | – | 14 | 17 | mAdc |
| Power Dissipation | $P_D$ | – | 168 | 204 | mW |

**DESIGN PARAMETERS,** Typical Values ($V^+$ = +12 Vdc, $T_A$ = +25°C, unless otherwise noted.)

| Parameter | Symbol | Frequency | | | | Unit |
|---|---|---|---|---|---|---|
| | | 455 kHz | 10.7 MHz | 45 MHz | 58 MHz | |
| Single–Ended Input Admittance | $g_{11}$ | 0.31 | 0.36 | 0.39 | 0.5 | mmho |
| | $b_{11}$ | 0.022 | 0.50 | 2.30 | 2.75 | |
| Input Admittance Variations with AGC | $\Delta g_{11}$ | – | – | 60 | – | µmho |
| (0 dB to 60 dB) | $\Delta b_{11}$ | – | – | 0 | – | |
| Differential Output Admittance | $g_{22}$ | 4.0 | 4.4 | 30 | 60 | µmho |
| | $b_{22}$ | 3.0 | 110 | 390 | 510 | |
| Output Admittance Variations with AGC | $\Delta g_{22}$ | – | – | 4.0 | – | µmho |
| (0 dB to 60 dB) | $\Delta b_{22}$ | – | – | 90 | – | |
| Reverse Transfer Admittance (Magnitude) | $\lvert y_{12} \rvert$ | < < 1.0 | < < 1.0 | < < 1.0 | < < 1.0 | µmho |
| Forward Transfer Admittance | | | | | | |
| Magnitude | $\lvert y_{21} \rvert$ | 160 | 160 | 200 | 180 | mmho |
| Angle (0 dB AGC) | < $y_{21}$ | –5.0 | –20 | –80 | –105 | Degrees |
| Angle (–30 dB AGC) | < $y_{21}$ | –3.0 | –18 | –69 | –90 | Degrees |
| Single–Ended Input Capacitance | $C_{in}$ | 7.2 | 7.2 | 7.4 | 7.6 | pF |
| Differential Output Capacitance | $C_O$ | 1.2 | 1.2 | 1.3 | 1.6 | pF |

**Figure 2. Typical Gain Reduction**

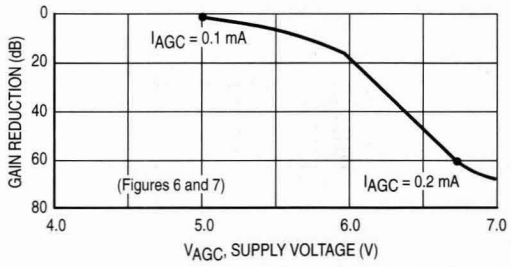
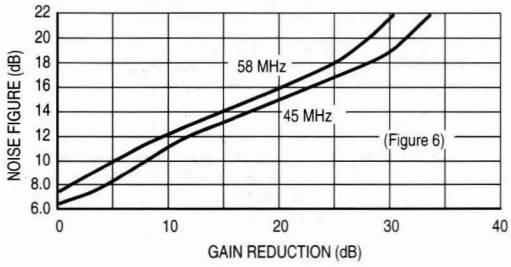



**Figure 3. Noise Figure versus Gain Reduction**

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## GENERAL OPERATING INFORMATION

The input amplifiers (Q1 and Q2) operate at constant emitter currents so that input impedance remains independent of AGC action. Input signals may be applied single–ended or differentially (for ac) with identical results. Terminals 4 and 6 may be driven from a transformer, but a dc path from either terminal to ground is not permitted.

AGC action occurs as a result of an increasing voltage on the base of Q4 and Q5 causing these transistors to conduct more heavily thereby shunting signal current from the interstage amplifiers Q3 and Q6. The output amplifiers are supplied from an active current source to maintain constant quiescent bias thereby holding output admittance nearly constant. Collector voltage for the output amplifier must be supplied through a center–tapped tuning coil to Pins 1 and 8. The 12 V supply (V+) at Pin 2 may be used for this purpose, but output admittance remains more nearly constant if a separate 15 V supply (V+ +) is used, because the base voltage on the output amplifier varies with AGC bias.

**Figure 4. Circuit Schematic**

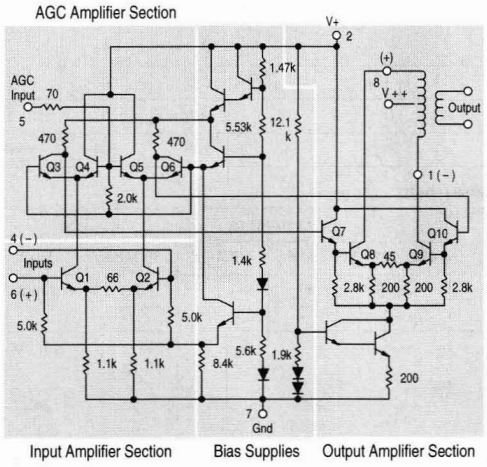



**Figure 5. Frequency Response Curve (45 MHz and 58 MHz)**

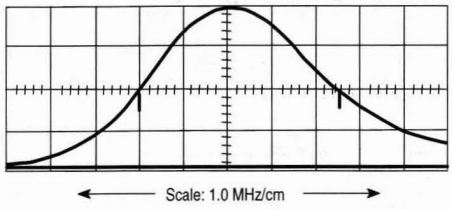
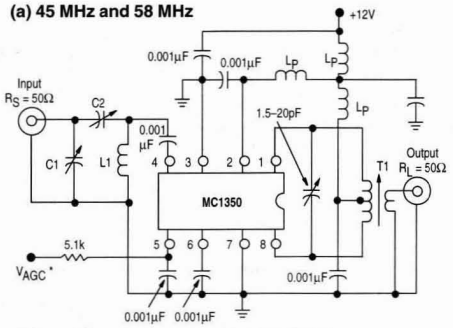



**Figure 6. Power Gain, AGC and Noise Figure Test Circuits**

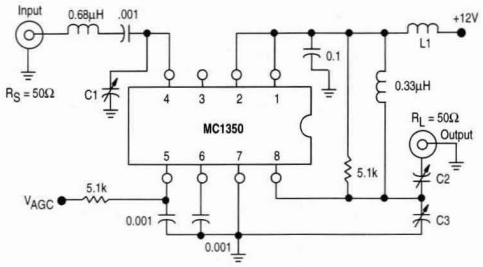
**(a) 45 MHz and 58 MHz**




*Connect to ground for maximum power gain test.
All power supply chokes (Lp), are self–resonant at input frequency. $L_P \geq 20\ k\Omega$.
See Figure 5 for Frequency Response Curve.

L1 @ 45 MHz = 7 1/4 Turns on a 1/4″ coil form
@ 58 MHz = 6 Turns on a 1/4″ coil form
T1 Primary Winding = 18 Turns on a 1/4″ coil form, center–tapped, #25 AWG
Secondary Winding = 2 Turns centered over Primary Winding @ 45 MHz
= 1 Turn @ 58 MHz
Slug = Carbonyl E or J

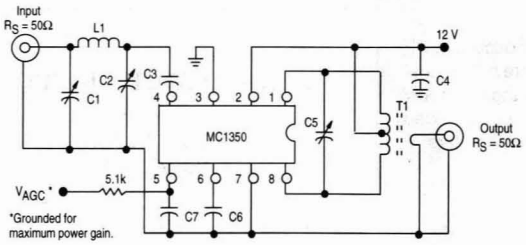
**(b) Alternate 45 MHz**




| L1 | Ferrite Core 14 Turns 28 S.W.G. |
|---|---|
| C1 | 5–25 pF |
| C2 | 5–25 pF |
| C3 | 5–25 pF |

| | 45 MHz | | 58 MHz | |
|---|---|---|---|---|
| L1 | 0.4 µH | Q ≥ 100 | 0.3 µH | Q ≥ 100 |
| T1 | 1.3 µH to 3.4 µH | Q ≥ 100 @ 2.0 µH | 1.2 µH to 3.8 µH | Q ≥ 100 @ 2.0 µH |
| C1 | 50 pF to160 pF | | 8.0 pF to 60 pF | |
| C2 | 8.0 pF to 60 pF | | 3.0 pF to 35 pF | |

**Figure 7. Power Gain and AGC Test Circuit (455 kHz and 10.7 MHz)**




| Component | Frequency | |
|---|---|---|
| | 455 kHz | 10.7 MHz |
| C1 | – | 80–450 pF |
| C2 | – | 5.0–80 pF |
| C3 | 0.05 µF | 0.001 µF |
| C4 | 0.05 µF | 0.05 µF |
| C5 | 0.001 µF | 36 pF |
| C8 | 0.05 µF | 0.05 µF |
| C7 | 0.05 µF | 0.05 µF |
| L1 | – | 4.6 µF |
| T1 | Note 1 | Note 2 |

**NOTES:** 1. Primary: 120 µH (center–tapped)
$Q_u$ = 140 at 455 kHz
Primary: Secondary turns ratio ≈ 13
2. Primary: 6.0 µH
Primary winding = 24 turns #36 AWG
(close–wound on 1/4″ dia. form)
Core = Carbonyl E or J
Secondary winding = 1–1/2 turns #36 AWG, 1/4″ dia.
(wound over center–tap)

**Figure 8. Single–Ended Input Admittance**

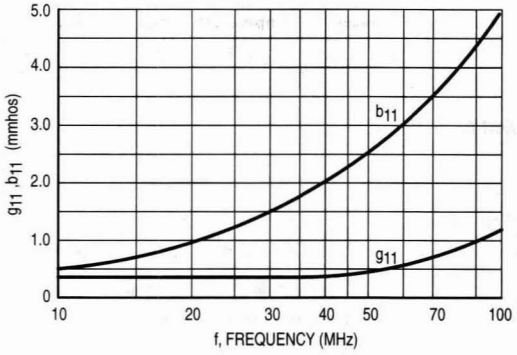



**Figure 9. Forward Transfer Admittance**

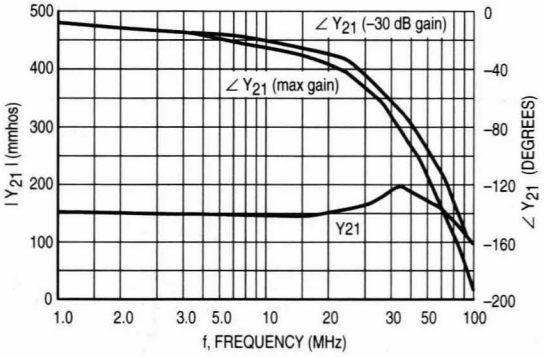



**Figure 10. Differential Output Admittance**

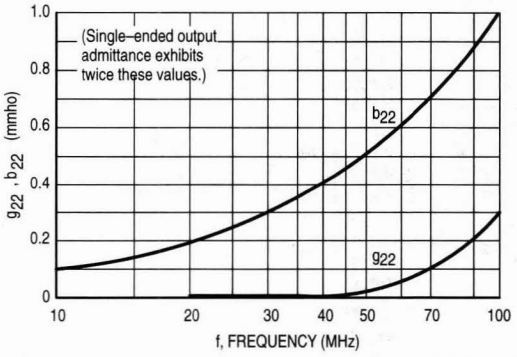
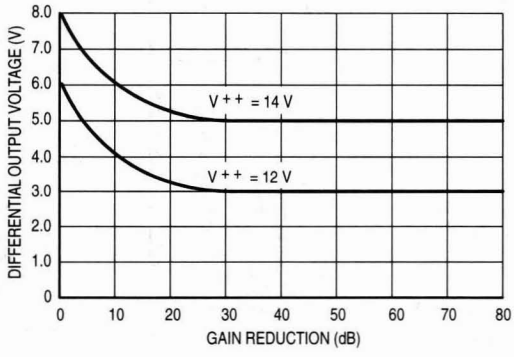



**Figure 11. Differential Output Voltage**

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MOTOROLA

# MC1374

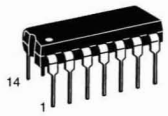
# TV Modulator Circuit

The MC1374 includes an FM audio modulator, sound carrier oscillator, RF oscillator, and RF dual input modulator. It is designed to generate a TV signal from audio and video inputs. The MC1374's wide dynamic range and low distortion audio make it particularly well suited for applications such as video tape recorders, video disc players, TV games and subscription decoders.

- Single Supply, 5.0 V to 12 V
- Channel 3 or 4 Operation
- Variable Gain RF Modulator
- Wide Dynamic Range
- Low Intermodulation Distortion
- Positive or Negative Sync
- Low Audio Distortion
- Few External Components

**TV MODULATOR CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

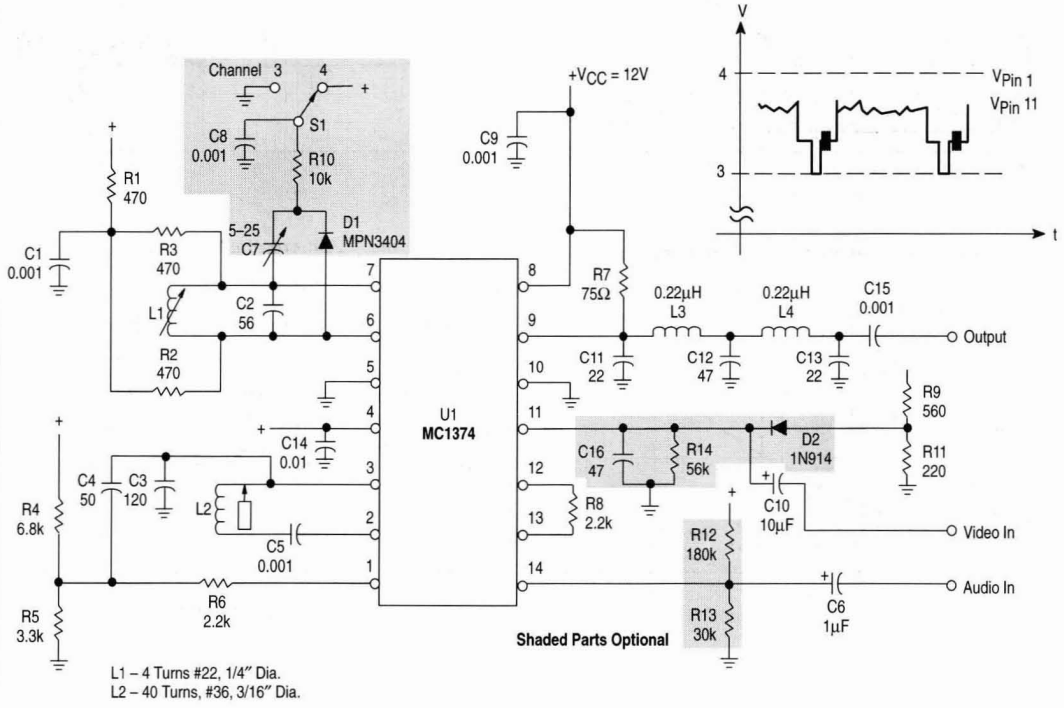



**P SUFFIX**
PLASTIC PACKAGE
CASE 646

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1374P | $T_A$ = 0° to +70°C | Plastic DIP |

**Figure 1. Simplified Application**

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Value | Unit |
|---|---|---|
| Supply Voltage | 14 | Vdc |
| Operating Ambient Temperature Range | 0 to +70 | °C |
| Storage Temperature Range | –65 to +150 | °C |
| Junction Temperature | 150 | °C |
| Power Dissipation Package<br>Derate above 25°C | 1.25<br>10 mW/°C | W |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 12 Vdc, $T_A$ = 25°C, $f_c$ = 67.25 MHz, Figure 4 circuit, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **AM OSCILLATOR/MODULATOR** | | | | |
| Operating Supply Voltage | 5.0 | 12 | 12 | V |
| Supply Current (Figure 1) | – | 13 | – | mA |
| Video Input Dynamic Range (Sync Amplitude) | 0.25 | 1.0 | 1.0 | V Pk |
| RF Output (Pin 9, R7 = 75 Ω, No External Load) | – | 170 | – | mV pp |
| Carrier Suppression | 36 | 40 | – | dB |
| Linearity (75% to 12.5% Carrier, 15 kHz to 3.58 MHz) | – | – | 2.0 | % |
| Differential Gain Distortion (IRE Test Signal) | 5.0 | 7.0 | 10 | % |
| Differential Phase Distortion (3.58 MHz IRE Test Signal) | – | 1.5 | 2.0 | Degrees |
| 920 kHz Beat (3.58 MHz @ 30%, 4.5 MHz @ 25%) | – | –57 | – | dB |
| Video Bandwidth (75 Ω Input Source) | 30 | – | – | MHz |
| Oscillator Frequency Range | – | 105 | – | MHz |
| Internal Resistance across Tank (Pin 6 to Pin 7)<br>Internal Capacitance across Tank (Pin 6 to Pin 7) | –<br>– | 1.8<br>4.0 | –<br>– | kΩ<br>pF |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 12 Vdc, 4.5 MHz, Test circuit of Figure 11, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **FM OSCILLATOR/MODULATOR** | | | | |
| Frequency Range of Modulator<br>Frequency Shift versus Temperature (Pin 14 open)<br>Frequency Shift versus $V_{CC}$ (Pin 14 open)<br>Output Amplitude (Pin 3 not loaded)<br>Output Harmonics, Unmodulated | 14<br>–<br>–<br>–<br>– | 4.5<br>0.2<br>–<br>900<br>– | 14<br>0.3<br>4.0<br>–<br>–40 | MHz<br>kHz/°C<br>kHz/V<br>mVpp<br>dB |
| Modulation Sensitivity 1.7 MHz<br>4.5 MHz<br>10.7 MHz | –<br>–<br>– | 0.20<br>0.24<br>0.80 | –<br>–<br>– | MHz/V |
| Audio Distortion (±25 kHz Deviation, Optimized Bias Pin 14)<br>Audio Distortion (±25 kHz Deviation, Pin 14 self biased)<br>Incidental AM (±25 kHz FM) | –<br>–<br>– | 0.6<br>1.4<br>2.0 | 1.0<br>–<br>– | % |
| Audio Input Resistance (Pin 14 to ground)<br>Audio Input Capacitance (Pin 14 to ground) | –<br>– | 6.0<br>5.0 | –<br>– | kΩ<br>pF |
| Stray Tuning Capacitance (Pin 3 to ground)<br>Effective Oscillator Source Impedance (Pin 3 to load) | –<br>– | 5.0<br>2.0 | –<br>– | pF<br>kΩ |

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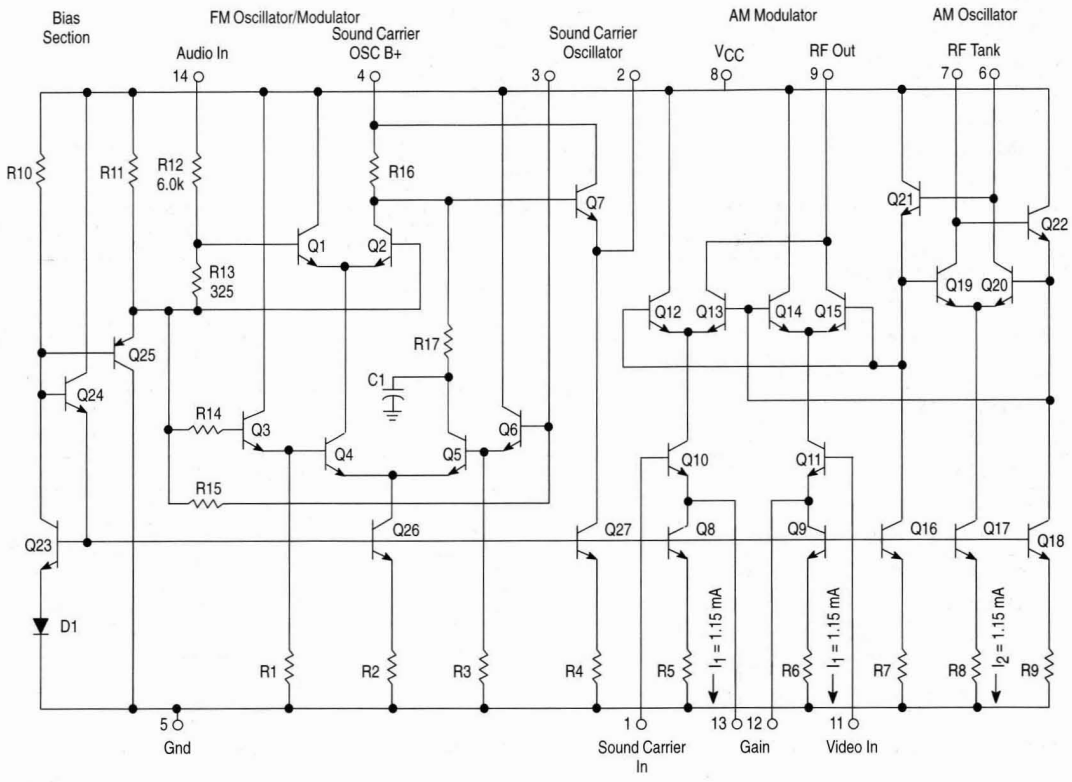
**Figure 2. TV Modulator**

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## GENERAL INFORMATION

The MC1374 contains an RF oscillator, RF modulator, and a phase shift type FM modulator, arranged to permit good printed circuit layout of a complete TV modulation system. The RF oscillator is similar to the one used in MC1373, and is coupled internally in the same way. Its frequency is controlled by an external tank on Pins 6 and 7, or by a crystal circuit, and will operate to approximately 105 MHz. The video modulator is a balanced type as used in the well known MC1496. Modulated sound carrier and composite video information can be put in separately on Pins 1 and 11 to minimize unwanted crosstalk. A single resistor on Pins 12 and 13 is selected to set the modulator gain. The RF output at Pin 9 is a current source which drives a load connected from Pin 9 to $V_{CC}$.

The FM system was designed specifically for the TV intercarrier function. For circuit economy, one phase shift circuit was built into the ship. Still, it will operate from 1.4 MHz to 14 MHz, low enough to be used in a cordless telephone base station (1.76 MHz), and high enough to be used as an FM IF test signal source (10.7 MHz). At 4.5 MHz, a deviation of ±25 kHz can be achieved with 0.6% distortion (typical).

In the circuit above, devices Q1 through Q7 are active in the oscillator function. Differential amplifier Q3, Q4, Q5, and Q6 acts as a gain stage, sinking current from input section Q1, Q2 and the phase shift network R17, C1. Input amplifier Q1, Q2 can vary the amount of "in phase" Q4 current to be combined with phase shifter current in load resistor R16. The R16 voltage is applied to emitter follower Q7 which drives an external L–C circuit. Feedback from the center of the L–C circuit back to the base of Q6 closes the loop. As audio input is applied which would offset the stable oscillatory phase, the frequency changes to counteract. The input to Pin 14 can include a dc feedback current for AFC over a limited range.

The modulated FM signal from Pin 3 is coupled to Pin 1 of the RF modulator and is then modulated onto the AM carrier.

### AM Section

The AM modulator transfer function in Figure 3 shows that the video input can be of either polarity (and can be applied at either input). When the voltages on Pin 1 and Pin 11 are equal, the RF output is theoretically zero. As the difference between $V_{Pin\ 11}$ and $V_{Pin\ 1}$ increases, the RF output increases linearly until all of the current from both $I_1$ current sources (Q8 and Q9) is flowing in one side of the modulator. This occurs when $\pm(V_{Pin11} - V_{Pin1}) = I_1\ R_G$, where $I_1$ is typically 1.15 mA. The peak–to–peak RF output is the $2I_1\ R_L$. Usually the value of $R_L$ is chosen to be 75 Ω to ease the design of the output filter and match into TV distribution systems. The theoretical range of input voltage and $R_G$ is quite wide, but noise and available sound level limit the useful video (sync tip) amplitude to between 0.25 Vpk and 1.0 Vpk. It is recommended that the value of $R_G$ be chosen so that only about half of the dynamic range will be used at sync tip level.

The operating window of Figure 5 shows a cross–hatched area where Pin 1 and Pin 11 voltages must always be in order to avoid saturation in any part of the modulator. The letter ϕ represents one diode drop, or about 0.75 V. The oscillator Pins 6 and 7 must be biased to a level of $V_{CC} - \phi - 2I_1\ R_L$ (or lower) and the input Pins 1 and 11 must always be at least 2ϕ below that. It is permissible to operate down to 1.6 V, saturating the current sources, but whenever possible, the minimum should be 3ϕ above ground.

The oscillator will operate dependably up to about 105 MHz with a broad range of tank circuit component values. It is desirable to use a small L and a large C to minimize the dependence on IC internal capacitance. An operating Q between 10 and 20 is recommended. The values of $R_1$, $R_2$ and $R_3$ are chosen to produce the desired Q and to set the Pin 6 and 7 dc voltage as discussed above. Unbalanced operation, i.e., Pin 6 or 7 bypassed to ground, is not recommended. Although the oscillator will still run, and the modulator will produce a useable signal, this mode causes substantial base–band video feedthrough. Bandswitching, as Figure 1 shows, can still be accomplished economically without using the unbalanced method.

The oscillator frequency with respect to temperature in the test circuit shows less than ±20 kHz total shift from 0° to 50°C as shown in Figure 7. At higher temperatures the slope approaches 2.0 kHz/°C. Improvement in this region would require a temperature compensating tuning capacitor of the N75 family.

Crystal control is feasible using the circuit shown in Figure 21. The crystal is a 3rd overtone series type, used in series resonance. The L1, C2 resonance is adjusted well below the crystal frequency and is sufficiently tolerant to permit fixed values. A frequency shift versus temperature of less than 1.0 Hz/°C can be expected from this approach. The resistors Ra and Rb are to suppress parasitic resonances.

Coupling of output RF to wiring and components on Pins 1 and 11 can cause as much as 300 kHz shift in carrier (at 67 MHz) over the video input range. A careful layout can keep this shift below 10 kHz. Oscillator may also be inadvertently coupled to the RF output, with the undesired effect of preventing a good null when $V_{11} = V_1$. Reasonable care will yield carrier rejection ratios of 36 to 40 dB below sync tip level carrier.

In television, one of the most serious concerns is the prevention of the intermodulation of color (3.58 MHz) and sound (4.5 MHz) frequencies, which causes a 920 kHz signal to appear in the spectrum. Very little (3rd order) nonlinearity is needed to cause this problem. The results in Figure 6 are unsatisfactory, and demonstrate that too much of the available dynamic range of the MC1374 has been used. Figures 8 and 10 show that by either reducing standard signal level, or reducing gain, acceptable results may be obtained.

At VHF frequencies, small imbalances within the device introduce substantial amounts of 2nd harmonic in the RF output. At 67 MHz, the 2nd harmonic is only 6 to 8 dB below the maximum fundamental. For this reason, a double pi low pass filter is shown in the test circuit of Figure 3 and works well for Channel 3 and 4 lab work. For a fully commercial application, a vestigial sideband filter will be required. The general form and approximate values are shown in Figure 19. It must be exactly aligned to the particular channel.

**Figure 3. AM Modulator Transfer Function**

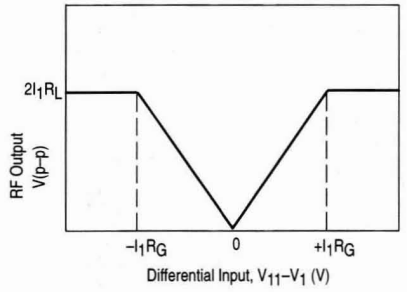



**Figure 4. AM Test Circuit**

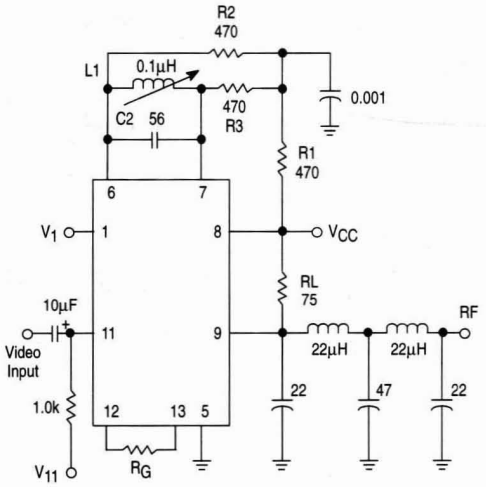


**Figure 5. The Operating Window**

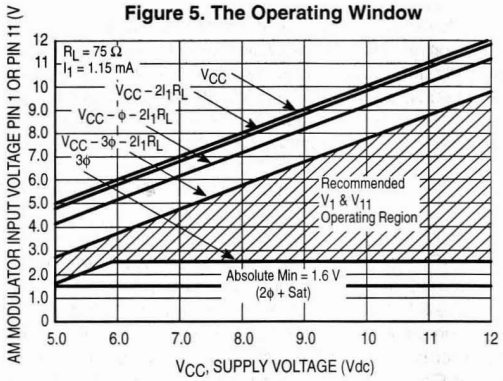



**Figure 6. 920 kHz Beat**

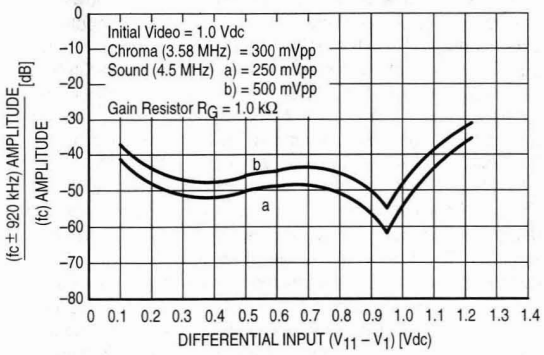

Initial Video = 1.0 Vdc
Chroma (3.58 MHz) = 300 mVpp
Sound (4.5 MHz) a) = 250 mVpp
b) = 500 mVpp
Gain Resistor $R_G$ = 1.0 kΩ
(fc ± 920 kHz) AMPLITUDE / (fc) AMPLITUDE [dB]
DIFFERENTIAL INPUT ($V_{11} - V_1$) [Vdc]

**Figure 7. RF Oscillator Frequency versus Temperature**

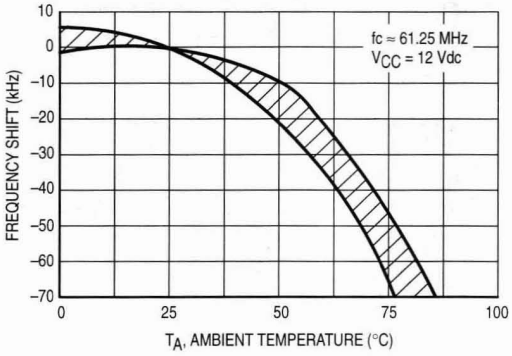



**Figure 8. 920 kHz Beat**

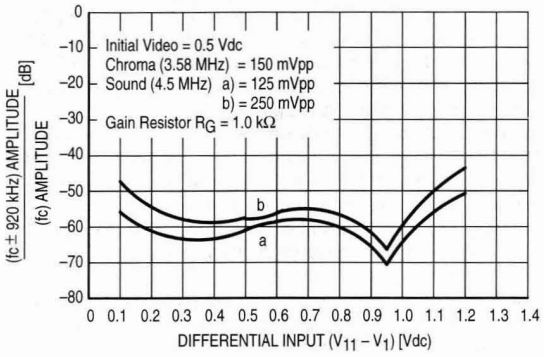

Initial Video = 0.5 Vdc
Chroma (3.58 MHz) = 150 mVpp
Sound (4.5 MHz) a) = 125 mVpp
b) = 250 mVpp
Gain Resistor $R_G$ = 1.0 kΩ
(fc ± 920 kHz) AMPLITUDE / (fc) AMPLITUDE [dB]
DIFFERENTIAL INPUT ($V_{11} - V_1$) [Vdc]

**Figure 9. RF Oscillator Frequency versus Supply Voltage**

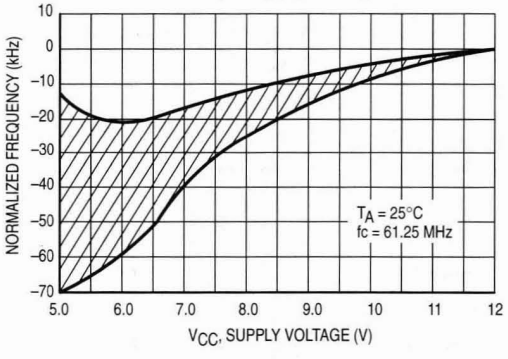
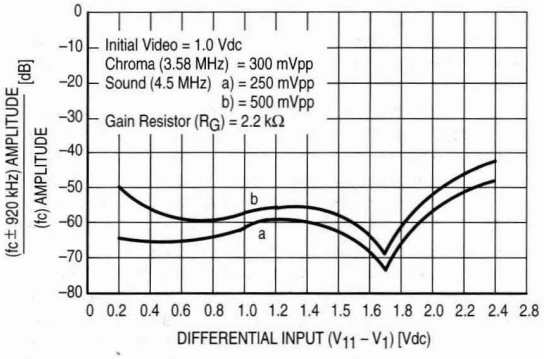



**Figure 10. 920 kHz Beat**


Initial Video = 1.0 Vdc
Chroma (3.58 MHz) = 300 mVpp
Sound (4.5 MHz) a) = 250 mVpp
b) = 500 mVpp
Gain Resistor ($R_G$) = 2.2 kΩ
(fc ± 920 kHz) AMPLITUDE / (fc) AMPLITUDE [dB]
DIFFERENTIAL INPUT ($V_{11} - V_1$) [Vdc]

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**FM Section**

The oscillator center is approximately the resonance of the inductor $L_2$ from Pin 2 to Pin 3 and the effective capacitance $C_3$ from Pin 3 to ground. For overall oscillator stability, it is best to keep $X_L$ in the range of 300 Ω to 1.0 kΩ.

The modulator transfer characteristic at 4.5 MHz is shown in Figure 15. Transfer curves at other frequencies have a very similar shape, but differ in deviation per input volt, as shown in Figures 13 and 17.

Most applications will not require DC connection to the audio input, Pin 14. However, some improvements can be achieved by the addition of biasing circuitry. The unaided device will establish its own Pin 14 bias at 4 θ, or about 3.0 V. This bias is a little too high for optimum modulation linearity. Figure 14 shows better than 2 to 1 improvement in distortion between the unaided device and pulling Pin 14 down to 2.6 V to 2.7 V. This can be accomplished by a simple divider, if the supply voltage is relatively constant.

The impedance of the divider has a bearing on the frequency versus temperature stability of the FM system. A divider of 180 kΩ and 30 kΩ (for $V_{CC}$ = 12 V) will give good temperature stabilization results. However, as Figure 18 shows, a divider is not a good method if the supply voltage varies. The designer must make the decisions here, based on considerations of economy, distortion and temperature requirements and power supply capability. If the distortion requirements are not stringent, then no bias components are needed. If, in this case, the temperature compensation needs to be improved in the high ambient area, the tuning capacitor from Pin 3 to ground can be selected from N75 or N150 temperature compensation types.

Another reason for DC input to Pin 14 is the possibility of automatic frequency control. Where high accuracy of inter–carrier frequency is required, it may be desirable to feed back the DC output of an AFC or phase detector for nominal carrier frequency control. Only limited control range could be used without adversely affecting the distortion performance, but very little frequency compensation will be needed.

One added convenience in the FM section is the separate Pin "oscillator B+" which permits disabling of the sound system during alignment of the AM section. Usually it can be hard wired to the $V_{CC}$ source without decoupling.

Standard practice in television is to provide pre–emphasis of higher audio frequencies at the transmitter and a matching de–emphasis in the TV receiver audio amplifier. The purpose of this is to counteract the fact that less energy is usually present in the higher frequencies, and also that fewer modulation sidebands are within the deviation window. Both factors degrade signal to noise ration. Pre–emphasis of 75 μs is standard practice. For cases where it has not been provided, a suitable pre–emphasis network is covered in Figure 20.

It would seem natural to take the FM system output from Pin 2, the emitter follower output, but this output is high in harmonic content. Taking the output from Pin 3 sacrifices somewhat in source impedance but results in a clean output fundamental, with all harmonics more than 40 dB down. This choice removes the need for additional filtering components. The source impedance of Pin 3 is approximately 2.0 kΩ, and the open circuit amplitude is about 900 mV pp for the test circuit shown in Figure 11.

The application circuit of Figure 1 shows the recommended approach to coupling the FM output from Pin 3 to the AM modulator input, Pin 1. The input impedance at Pin 1 is very high, so the intercarrier level is determined by the source impedance of Pin 3 driving through C4 into the video bias circuit impedance of R4 and R5, about 2.2 k. This provides an intercarrier level of 500 mV pp, which is correct for the 1.0 V peak video level chosen in this design. Resistor R6 and the input capacitance of Pin 1 provide some decoupling of stray pickup of RF oscillator or AM output which may be coupled to the sound circuitry.

**Figure 11. FM Test Circuit**

| $f_o$ (MHz) | C3 (pF) | L2 (μH) |
|---|---|---|
| 10.7 | 12 | 10 |
| 4.5 | 120 | 10 |
| 1.76 | 200 | 40 |

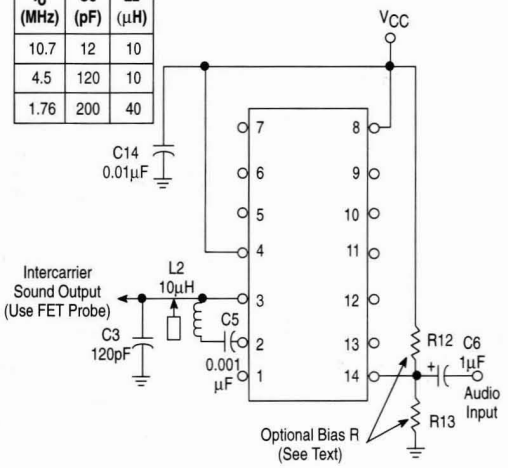


**Figure 12. Modulator Sensitivity**

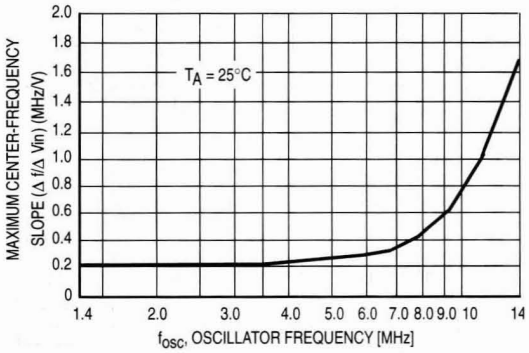


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**Figure 13. Modulator Transfer Function**

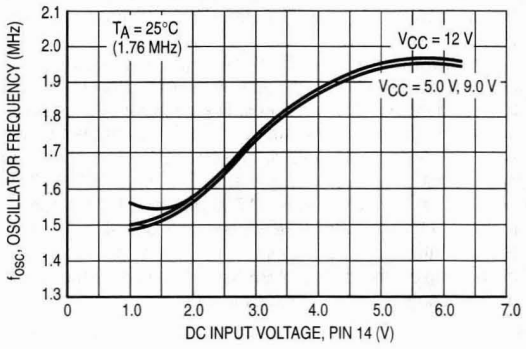


**Figure 14. Distortion versus Modulation Depth**

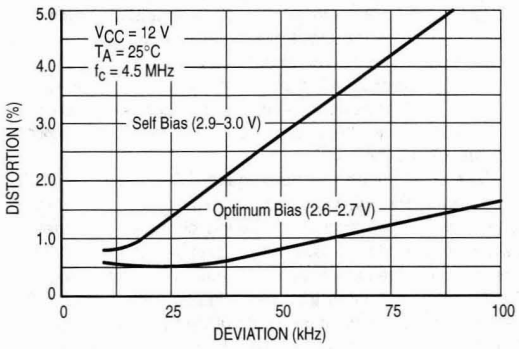


**Figure 15. Modulator Transfer Function**

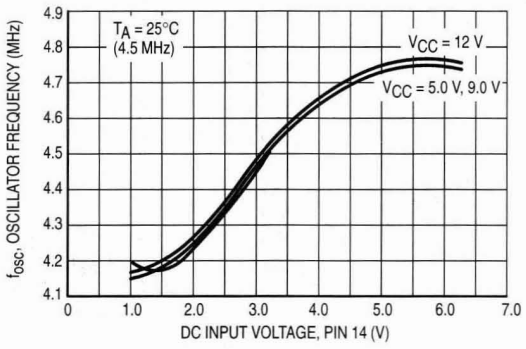


**Figure 16. FM System Frequency versus Temperature**

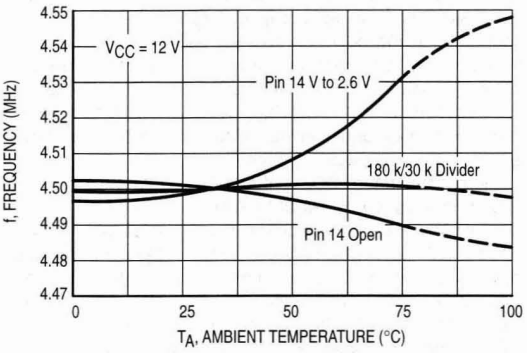


**Figure 17. Modulator Transfer Function**

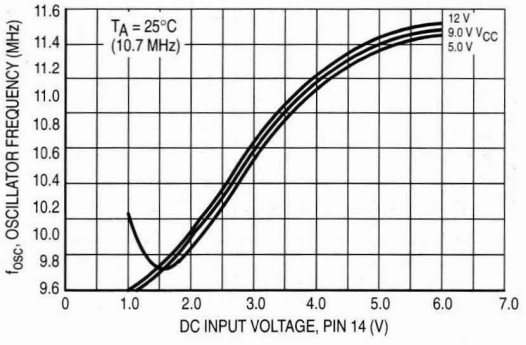


**Figure 18. FM System Frequency versus $V_{CC}$**

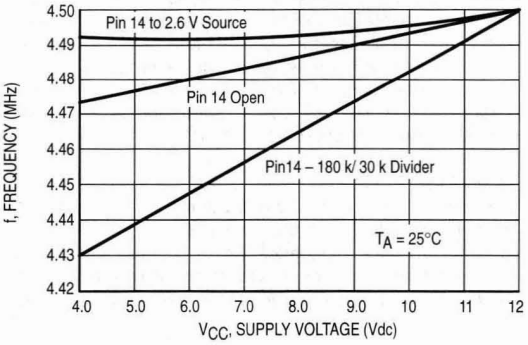


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**Figure 19. A Channel 4 Vestigial Sideband Filter**

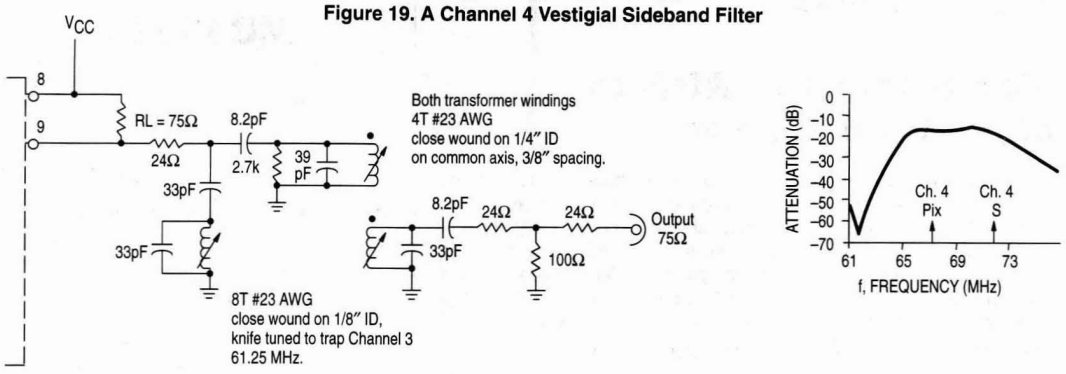



**Figure 20. Audio Pre–Emphasis Circuit**

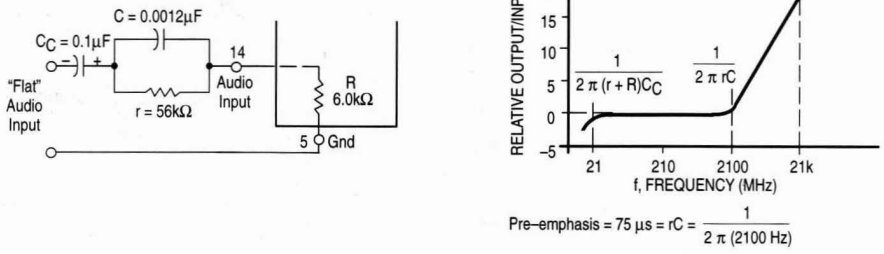
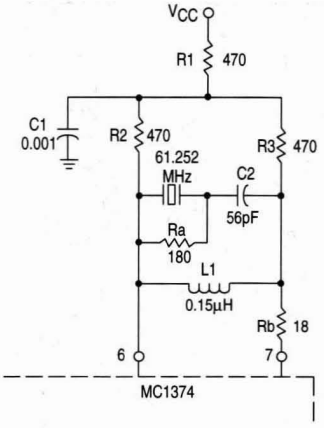



**Figure 21. Crystal Controlled RF Oscillator for Channel 3, 61.25 MHz**




**NOTE: See Application Note AN829 for further information.**

MOTOROLA

# MC1377

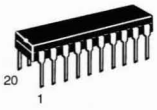
# Color Television RGB to PAL/NTSC Encoder

The MC1377 will generate a composite video from baseband red, green, blue, and sync inputs. On board features include: a color subcarrier oscillator; voltage controlled 90° phase shifter; two double sideband suppressed carrier (DSBSC) chroma modulators; and RGB input matrices with blanking level clamps. Such features permit system design with few external components and accordingly, system performance comparable to studio equipment with external components common in receiver systems.

- Self–contained or Externally Driven Reference Oscillator
- Chroma Axes, Nominally 90° (±5°), are Optionally Trimable
- PAL/NTSC Compatible
- Internal 8.2 V Regulator

**COLOR TELEVISION RGB to PAL/NTSC ENCODER**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 738

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1377DW | $T_A$ = 0° to +70°C | SO–20L |
| MC1377P | | Plastic DIP |

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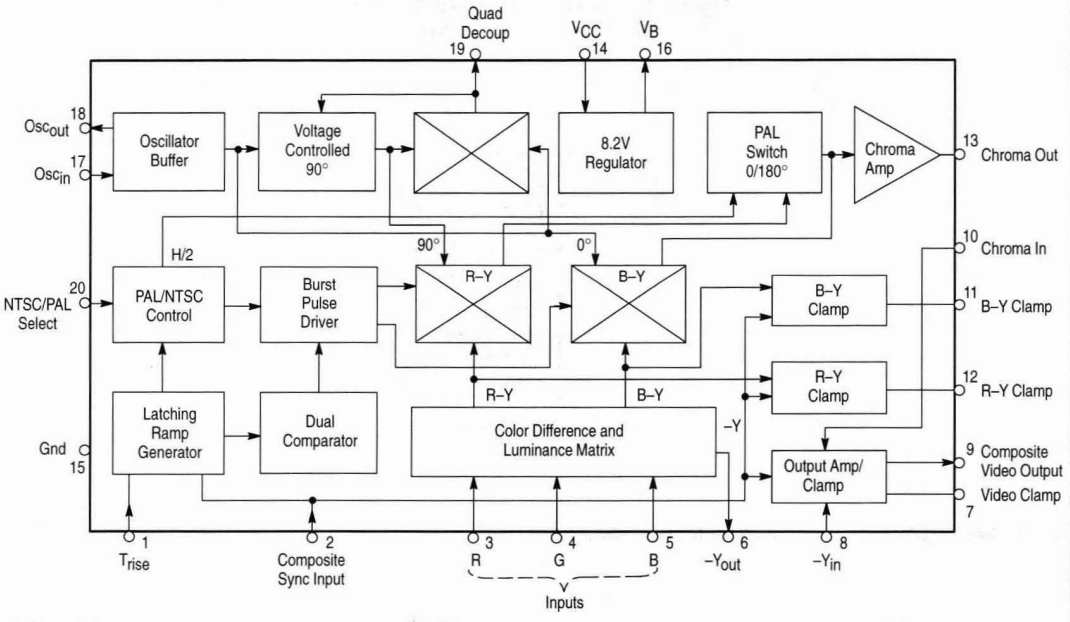
**Figure 1. Representative Block Diagram**



## MAXIMUM OPERATING CONDITIONS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 15 | Vdc |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Power Dissipation Package<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |
| Operating Temperature | $T_A$ | 0 to +70 | °C |

## RECOMMENDED OPERATING CONDITIONS

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Supply Voltage | 10 | 12 | 14 | Vdc |
| $I_B$ Current (Pin 16) | 0 | – | –10 | mA |
| Sync, Blanking Level (DC level between pulses, see Figure 9e)<br>Sync Tip Level (see Figure 9e)<br>Sync Pulse Width (see Figure 9e) | 1.7<br>–0.5<br>2.5 | –<br>0<br>– | 8.2<br>0.9<br>5.2 | Vdc<br><br>µs |
| R, G, B Input (Amplitude)<br>R, G, B Peak Levels for DC Coupled Inputs, with Respect to Ground | –<br>2.2 | 1.0<br>– | –<br>4.4 | $V_{pp}$<br>V |
| Chrominance Bandwidth (Non–comb Filtered Applications), (6 dB) | 0.5 | 1.5 | 2.0 | MHz |
| Ext. Subscarrier Input (to Pin 17) if On–Chip Oscillator is not used. | 0.5 | 0.7 | 1.0 | $V_{pp}$ |

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 12 Vdc, $T_A$ = 25°C, circuit of Figure 7, unless otherwise noted.)

| Characteristics | | Pins | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **SUPPLY CURRENT** | | | | | | | |
| Supply Current into $V_{CC}$, No Load, on Pin 9.<br>Circuit Figure 7 | $V_{CC}$ = 10 V<br>$V_{CC}$ = 11 V<br>$V_{CC}$ = 12 V<br>$V_{CC}$ = 13 V<br>$V_{CC}$ = 14 V | 14 | $I_{CC}$ | –<br>–<br>20<br>–<br>– | 33<br>34<br>35<br>36<br>37 | –<br>–<br>40<br>–<br>– | mA |
| **VOLTAGE REGULATOR** | | | | | | | |
| $V_B$ Voltage ($I_B$ = –10 mA, $V_{CC}$ = 12 V, Figure 7)<br>Load Regulation (0 < $I_B$ ≤ 10 mA, $V_{CC}$ = 12 V)<br>Line Regulation ($I_B$ = 0 mA, 10 V < $V_{CC}$ < 14 V) | | 16 | $V_B$<br>$Reg_{load}$<br>$Reg_{line}$ | 7.7<br>–20<br>– | 8.2<br>120<br>4.5 | 8.7<br>+30<br>– | Vdc<br>mV<br>mV/V |
| **OSCILLATOR AND MODULATION** | | | | | | | |
| Oscillator Amplitude with 3.58 MHz/4.43 MHz crystal | | 17 | Osc | – | 0.6 | – | $V_{pp}$ |
| Subcarrier Input: Resistance at 3.58 MHz<br>4.43 MHz | | 17 | $R_{osc}$ | –<br>– | 5.0<br>4.0 | –<br>– | kΩ |
| Capacitance | | | $C_{osc}$ | – | 2.0 | – | pF |
| Modulation Angle (R–Y) to (B–Y)<br>Angle Adjustment (R–Y)<br>DC Bias Voltage | | –<br>19<br>19 | Ø<br>ΔØ<br>$V_{19}$ | –<br>–<br>– | ±5<br>0.25<br>6.4 | –<br>–<br>– | Deg<br>Deg/µA<br>Vdc |
| **CHROMINANCE AND LUMINANCE** | | | | | | | |
| Chroma Input DC Level<br>Chroma Input Level for 100% Saturation | | 10 | $V_{in}$ | –<br>– | 4.0<br>0.7 | –<br>– | Vdc<br>$V_{pp}$ |
| Chroma Input: Resistance<br>Capacitance | | | $R_{in}$<br>$C_{in}$ | –<br>– | 10<br>2.0 | –<br>– | kΩ<br>pF |
| Chroma DC Output Level<br>Chroma Output Level at 100% Saturation | | 13 | $V_{out}$ | 8.9<br>– | 10<br>1.0 | 10.9<br>– | Vdc<br>$V_{pp}$ |
| Chroma Output Resistance | | | $R_{out}$ | – | 50 | – | Ω |
| Luminance Bandwidth (–3.0 dB), Less Delay Line | | 9 | $BW_{Luma}$ | – | 8.0 | – | MHz |

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**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 12 Vdc, $T_A$ = 25°C, circuit of Figure 7, unless otherwise noted.)

| Characteristics | Pins | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **VIDEO INPUT** | | | | | | |
| R, G, B Input DC Levels | 3, 4, 5 | RGB | 2.8 | 3.3 | 3.8 | Vdc |
| R, G, B Input for 100% Color Saturation | | | – | 1.0 | – | $V_{pp}$ |
| R, G, B Input: Resistance | | $R_{RGB}$ | 8.0 | 10 | 17 | kΩ |
| Capacitance | | $C_{RGB}$ | – | 2.0 | – | pF |
| Sync Input Resistance (1.7 V < Input < 8.2) | 2 | Sync | – | 10 | – | kΩ |
| **COMPOSITE VIDEO OUTPUT** | | | | | | |
| Composite Output, 100% Saturation (see Figure 8d) — Sync | 9 | $CV_{out}$ | – | 0.6 | – | $V_{pp}$ |
| Luminance | | | – | 1.4 | – | |
| Chroma | | | – | 1.7 | – | |
| Burst | | | – | 0.6 | – | |
| Output Impedance (Note 1) | | $R_{video}$ | – | 50 | – | Ω |
| Subcarrier Leakage in Output (Note 2) | | $V_{lk}$ | – | 20 | – | $mV_{pp}$ |

**NOTES:** 1. Output Impedance can be reduced to less than 10 Ω by using a 150 Ω output load from Pin 9 to ground. Power supply current will increase to about 60 mA.
2. Subcarrier leakage can be reduced to less than 10 mV with optional circuitry (see Figure 12).

## PIN FUNCTION DESCRIPTIONS

| Symbol | Pin | Description |
|---|---|---|
| $t_r$ | 1 | External components at this pin set the rise time of the internal ramp function generator (see Figure 10). |
| Sync | 2 | Composite sync input. Presents 10 kΩ resistance to input. |
| R | 3 | Red signal input. Presents 10 kΩ impedance to input. 1.0 $V_{pp}$ required for 100% saturation. |
| G | 4 | Green signal input. Presents 10 kΩ impedance to input. 1.0 $V_{pp}$ required for 100% saturation. |
| B | 5 | Blue signal Input. Presents 10 kΩ impedance to input. 1.0 $V_{pp}$ required for 100% saturation. |
| $-Y_{out}$ | 6 | Luma (–Y) output. Allows external setting of luma delay time. |
| $V_{clamp}$ | 7 | Video Clamp pin. Typical connection is a 0.01 µF capacitor to ground. |
| $-Y_{in}$ | 8 | Luma (–Y) input. Presents 10 kΩ input impedance. |
| $CV_{out}$ | 9 | Composite Video output. 50 Ω output impedance. |
| $Chroma_{In}$ | 10 | Chroma input. Presents 10 kΩ input impedance. |
| $B–Y_{clamp}$ | 11 | B–Y clamp. Clamps B–Y during blanking with a 0.1 µF capacitor to ground. Also used with R–Y clamp to null residual color subcarrier in output. |
| $R–Y_{clamp}$ | 12 | R–Y clamp. Clamps R–Y during blanking with a 0.1 µF capacitor to ground. Also used with B–Y clamp to null residual color subcarrier in output. |
| $Chroma_{Out}$ | 13 | Chroma output. 50 Ω output impedance. |
| $V_{CC}$ | 14 | Power supply pin for the IC; +12, ± 2.0 V, required at 35 mA (typical). |
| Gnd | 15 | Ground pin. |
| $V_B$ | 16 | 8.2 V reference from an internal regulator capable of delivering 10 mA to external circuitry. |
| $Osc_{in}$ | 17 | Oscillator input. A transistor base presents 5.0 kΩ to an external subcarrier input, or is available for constructing a Colpitts oscillator (see Figure 4). |
| $Osc_{out}$ | 18 | Oscillator output. The emitter of the transistor, with base access at Pin 17, is accessible for completing the Colpitts oscillator. See Figure 4. |
| $\varnothing_m$ | 19 | Quad decoupler. With external circuitry, R–Y to B–Y relative angle errors can be corrected. Typically, requires a 0.01 µF capacitor to ground. |
| NTSC/PAL Select | 20 | NTSC/PAL switch. When grounded, the MC1377 is in the NTSC mode; if unconnected, in the PAL mode. |

## FUNCTIONAL DESCRIPTION

**Figure 2. Power Supply and $V_B$**

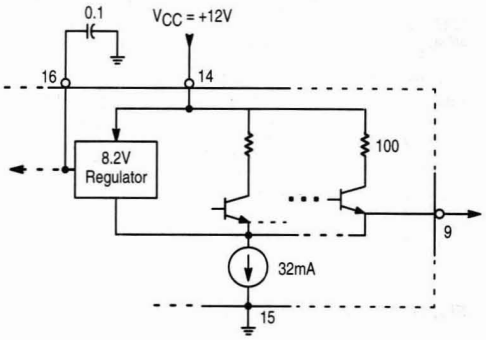



**Figure 3. RGB Input Circuitry**

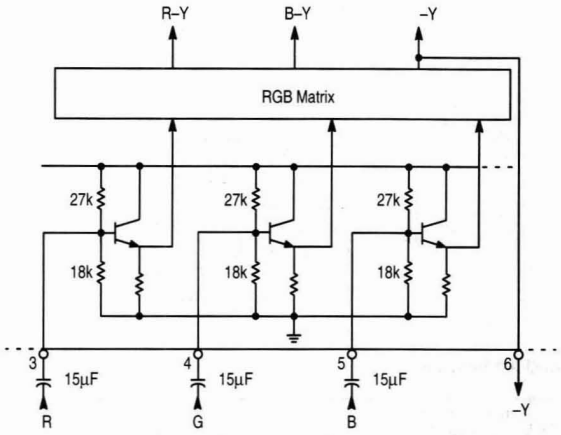
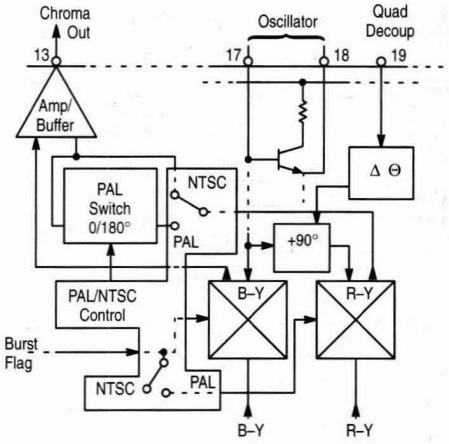



**Figure 4. Chroma Section**




### Power Supply and $V_B$ (8.2 V Regulator)

The MC1377 pin for power supply connection is Pin 14. From the supply voltage applied to this pin, the IC biases internal output stages and is used to power the 8.2 V internal regulator ($V_B$ at Pin 16) which biases the majority of internal circuitry. The regulator will provide a nominal 8.2 V and is capable of 10 mA before degradation of performance. An equivalent circuit of the supply and regulator is shown in Figure 2.

### R, G, B Inputs

The RGB inputs are internally biased to 3.3 V and provide 10 kΩ of input impedance. Figure 3 shows representative input circuitry at Pins 3, 4, and 5.

The input coupling capacitors of 15 µF are used to prevent tilt during the 50/60 Hz vertical period. However, if it is desired to avoid the use of the capacitors, then inputs to Pins 3, 4, and 5 can be dc coupled provided that the signal levels are always between 2.2 V and 4.4 V.

After input, the separate RGB information is introduced to the matrix circuitry which outputs the R–Y, B–Y, and –Y signals. The –Y information is routed out at Pin 6 to an external delay line (typically 400 ns).

### DSBSC Modulators and 3.58 MHz Oscillator

The R–Y and B–Y outputs (see (B–Y)/(R–Y) Axes versus I/Q Axes, Figure 22) from the matrix circuitry are amplitude modulated onto the 3.58/4.43 MHz subcarrier. These signals are added and color burst is included to produce composite chroma available at Pin 13. These functions plus others, depending on whether NTSC or PAL operation is chosen, are performed in the chroma section. Figure 4 shows a block diagram of the chroma section.

The MC1377 has two double balanced mixers, and regardless of which mode is chosen (NTSC or PAL), the mixers always perform the same operation. The B–Y mixer modulates the color subcarrier directly, the R–Y mixer receives a 90° phase shifted color subcarrier before being modulated by the R–Y baseband information. Additional operations are then performed on these two signals to make them NTSC or PAL compatible.

In the NTSC mode, the NTSC/PAL control circuitry allows an inverted burst of 3.58 MHz to be added only to the B–Y signal. A gating pulse or "burst flag" from the timing section permits color burst to be added to the B–Y signal. This color burst is 180° from the B–Y signal and 90° away from the R–Y signal (see Figure 22) and permits decoding of the color information. These signals are then added and amplified before being output, at Pin 13, to be bandpassed and then reintroduced to the IC at Pin 10.

In the PAL mode, NTSC/PAL control circuitry allows an inverted 4.43 MHz burst to be added to both R–Y and B–Y equally to produce the characteristic PAL 225°/135 burst phase. Also, the R–Y information is switched alternately from 180° to 0° of its original position and added to the B–Y information to be amplified and output.

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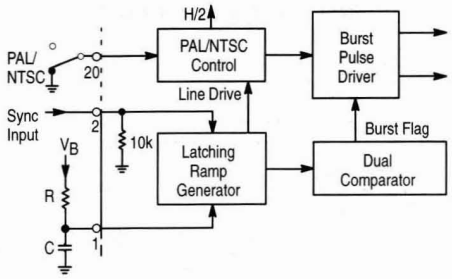
### Timing Circuitry

The composite sync input at Pin 2 performs three important functions: it provides the timing (but not the amplitude) for the sync in the final output; it drives the black level clamps in the modulators and output amplifier; and it triggers the ramp generator at Pin 1, which produces burst envelope and PAL switching. A representative block diagram of the timing circuitry is shown in Figure 5.

In order to produce a color burst, a burst envelope must be generated which "gates" a color subcarrier into the R–Y and B–Y modulators. This is done with the ramp generator at Pin 1.

The ramp generator at Pin 1 is an R–C type in which the pin is held low until the arrival of the *leading* edge of sync. The rising ramp function, with time constant R–C, passes through two level sensors – the first one starts the gating pulse and the second stops it (see Figure 10). Since the "early" part of the exponential is used, the timing provided is relatively accurate from chip–to–chip and assembly–to–assembly. Fixed components are usually adequate. The ramp continues to rise for more than half of the line interval, thereby inhibiting burst generation on "half interval" pulses on vertical front and back porches. The ramp method will produce burst on the vertical front and back "porches" at full line intervals.

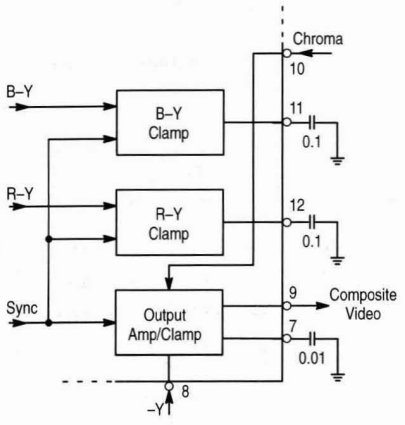
**Figure 5. Timing Circuitry**




### R–Y, B–Y Clamps and Output Clamp/Amplifier

The sync signal, shown in the block diagram of Figure 6, drives the R–Y and B–Y clamps which clamp the R–Y and B–Y signals to reference black during the blanking periods. The output amplifier/clamp provides this same function plus combines and amplifies the chroma and luma components for composite video output.

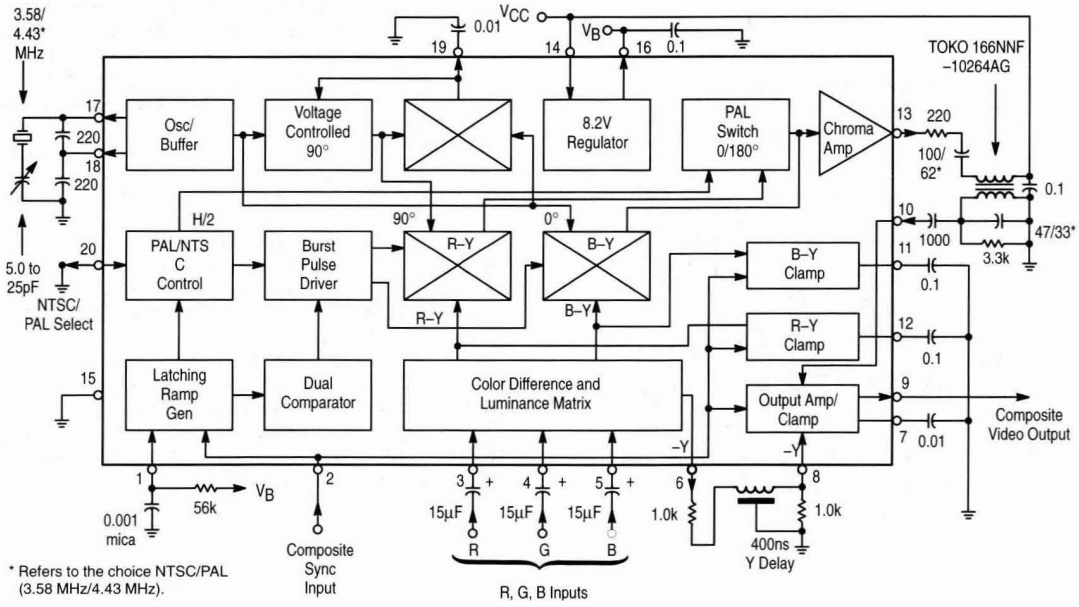
**Figure 6. R–Y, B–Y and Output Amplifier Clamps**




### Application Circuit

Figure 7 illustrates the block diagram of the MC1377 and the external circuitry required for typical operation.

**Figure 7. Block Diagram and Application Circuit**



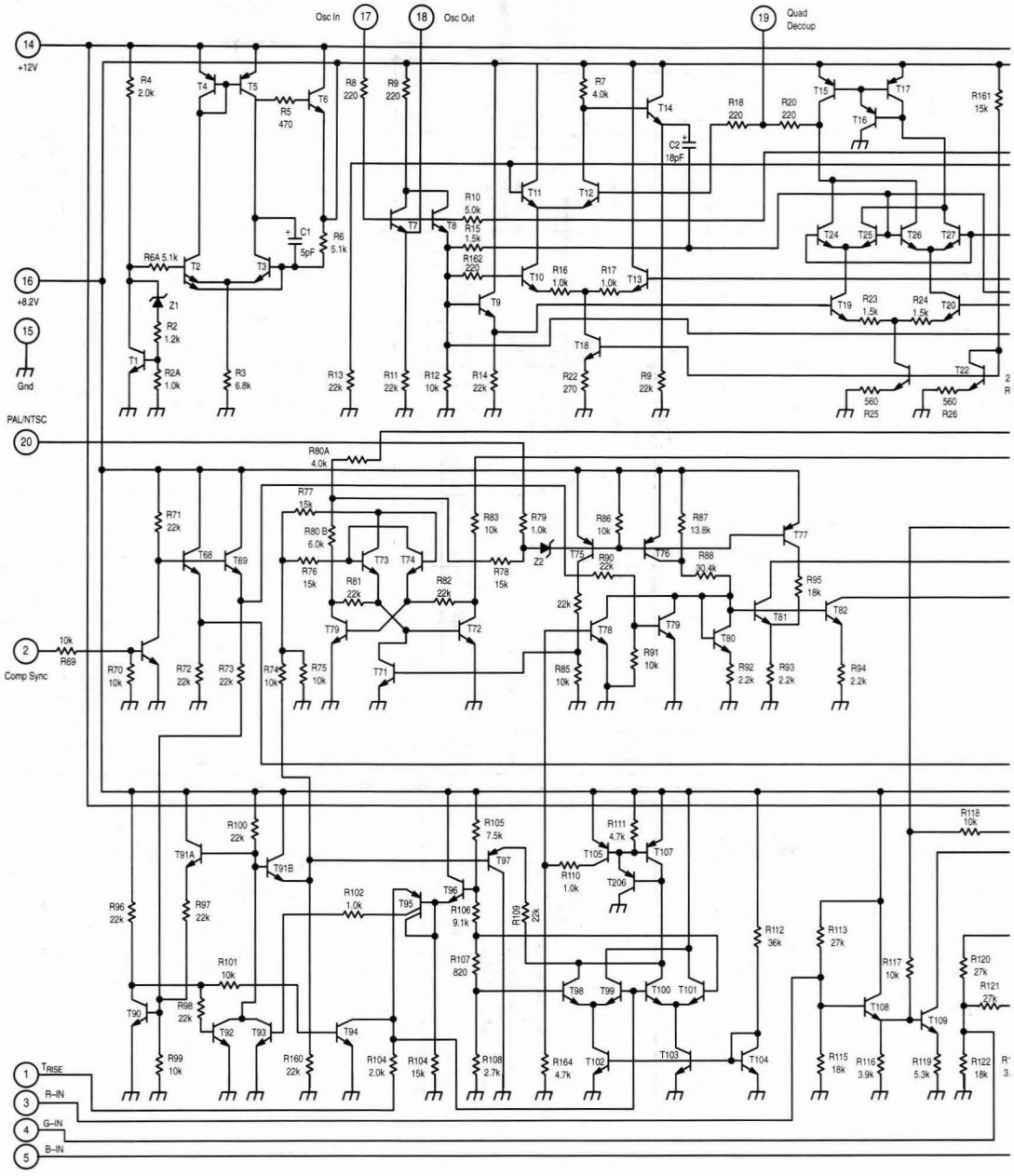
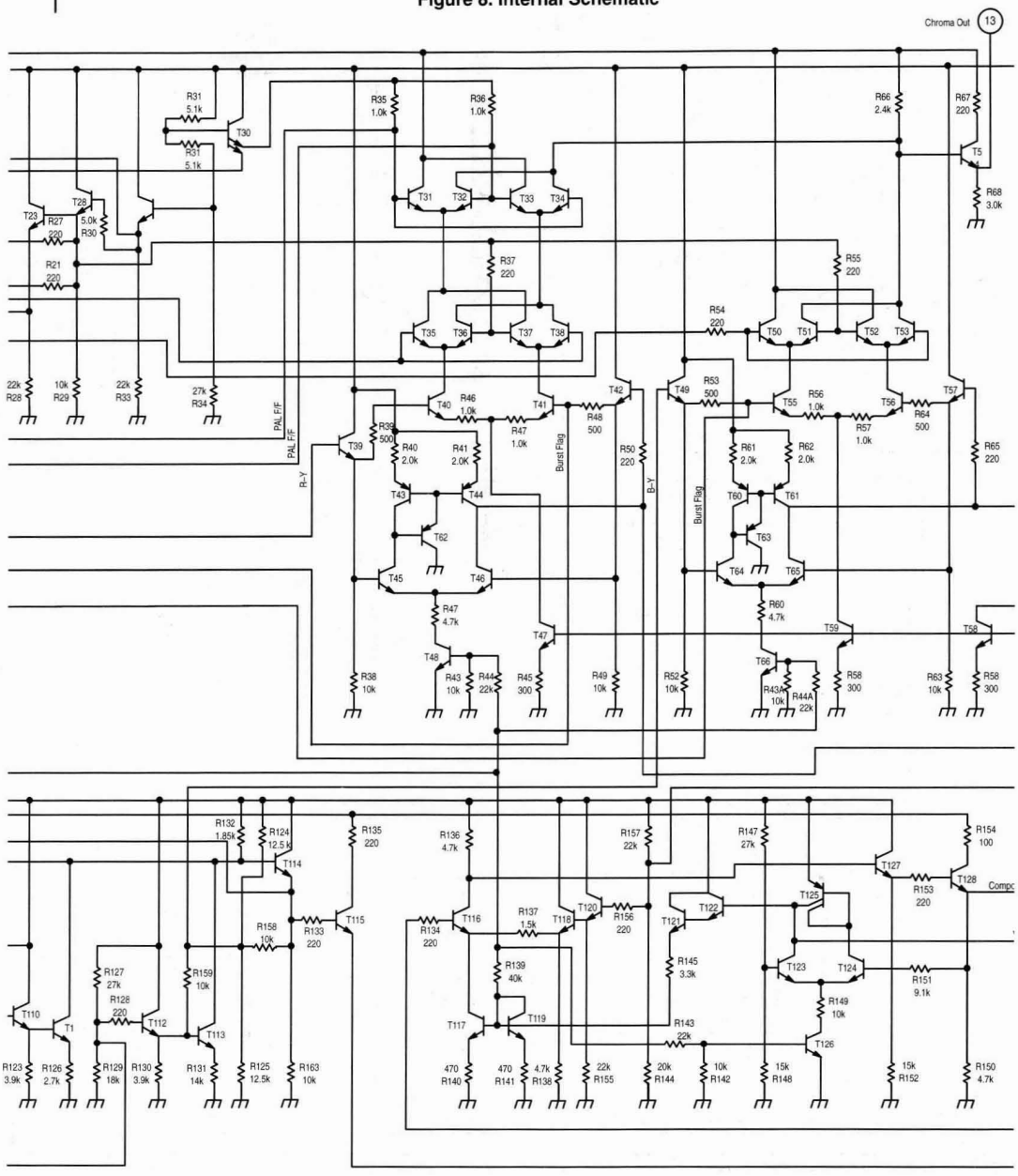

Osc In
17
18
Osc Out
19
Quad Decoup
14
+12V
16
+8.2V
15
Gnd
PAL/NTSC
20
2
Comp Sync
1
TRISE
3
R–IN
4
G–IN
5
B–IN

**Figure 8. Internal Schematic**

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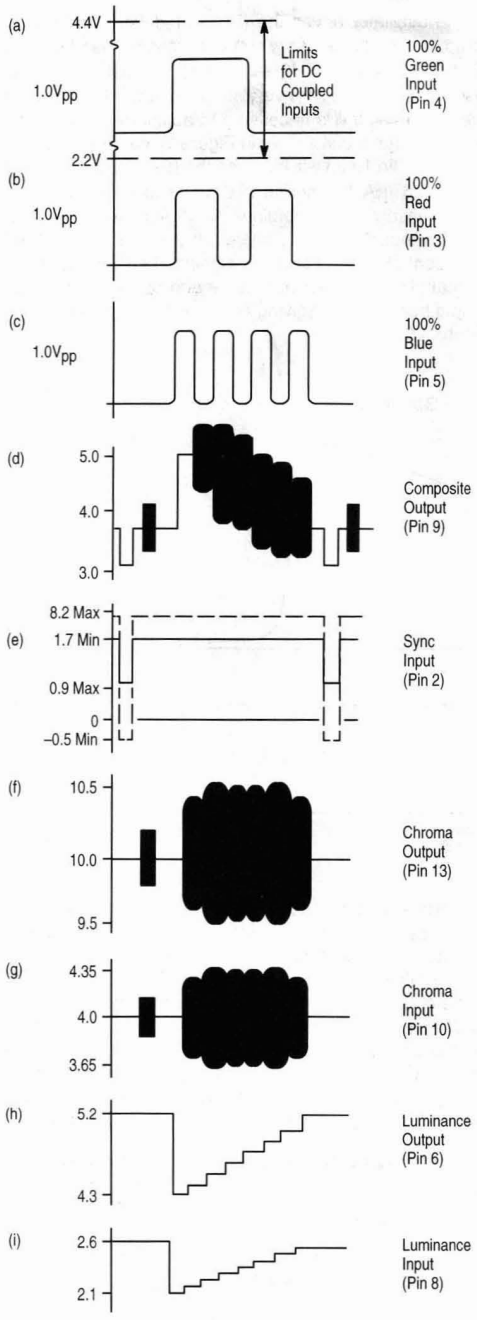
## APPLICATION INFORMATION

**Figure 8. Signal Voltages (Circuit Values of Figure 7)**




### R, G, B Input Levels

The signal levels into Pins 3, 4, 5 should be 1.0 $V_{pp}$ for fully saturated, standard composite video output levels as shown in Figure 9(d). The inputs require 1.0 $V_{pp}$ since the internally generated sync pulse and color burst are at fixed and predetermined amplitudes.

Further, it is essential that the portion of each input which occurs during the sync interval represent black for that input since that level will be clamped to reference black in the color modulators and output stage. This implies that a refinement, such as a difference between black and blanking levels, must be incorporated in the RGB input signals.

If Y, R–Y, B–Y and burst flag components are available and the MC1377 is operating in NTSC, inputs may be as follows: the Y component can be coupled through a 15 pF capacitor to Pins 3, 4 and 5 tied together; the (–[R–Y]) component can be coupled to Pin 12 through a 0.1 μF capacitor, and the (–[B–Y]) and burst flag components can be coupled to Pin 11 in a similar manner.

### Sync Input

As shown in Figure 9(e), the sync input amplitude can be varied over a wide latitude, but will require bias pull–up from most sync sources. The important requirements are:

1) The voltage level between sync pulses must be between 1.7 V and 8.2 V, see Figure 9(e).
2) The voltage level for the sync tips must be between +0.9 V and – 0.5 V, to prevent substrate leakage in the IC, see Figure 9(e).
3) The width of the sync pulse should be no longer than 5.2 μs and no shorter than 2.5 μs.

For PAL operation, correctly serrated vertical sync is necessary to properly trigger the PAL divider. In NTSC mode, simplified "block" vertical sync can be used but the loss of proper horizontal timing may cause "top hook" or "flag waving" in some monitors. An interesting note is that composite video can be used directly as a sync signal, provided that it meets the sync input criteria.

### Latching Ramp (Burst Flag) Generator

The recommended application is to connect a close tolerance (5%) 0.001 μF capacitor from Pin 1 to ground and a resistor of 51 kΩ or 56 kΩ from Pin 1 to $V_B$ (Pin 16). This will produce a burst pulse of 2.5 μs to 3.5 μs in duration, as shown in Figure 10. As the ramp on Pin 1 rises toward the charging voltage of 8.2 V, it passes first through a burst "start threshold" at 1.0 V, then a "stop threshold" at 1.3 V, and finally a ramp reset threshold at 5.0 V. If the resistor is reduced to 43 kΩ, the ramp will rise more quickly, producing a narrower and earlier burst pulse (starting approx. 0.4 μs after sync and about 0.6 μs wide). The burst will be wider and later if the resistor is raised to 62 kΩ, but more importantly, the 5.0 V reset point may not be reached in one full line interval, resulting in loss of alternate burst pulses.

As mentioned earlier, the ramp method does produce burst at full line intervals on the "vertical porches." If this is not desired, and the MC1377 is operating in the NTSC mode, burst flag may be applied to Pin 1 provided that the tip of the

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pulse is between 1.0 Vdc and 1.3 Vdc. In PAL mode this method is not suitable, since the ramp isn't available to drive the PAL flip–flop. Another means of inhibiting the burst pulse is to set Pin 1 either above 1.3 Vdc or below 1.0 Vdc for the duration that burst is not desired.

**Color Reference Oscillator/Buffer**

As stated earlier in the general description, there is an on–board common collector Colpitts color reference oscillator with the transistor base at Pin 17 and the emitter at Pin 18. When used with a common low–cost TV crystal and capacitive divider, about 0.6 $V_{pp}$ will be developed at Pin 17. The frequency adjustment can be done with a series 30 pF trimmer capacitor over a total range of about 1.0 kHz. Oscillator frequency should be adjusted for each unit, keeping in mind that most monitors and receivers can pull in 1200 Hz.

If an external color reference is to be used exclusively, it must be continuous. The components on Pins 17 and 18 can be removed, and the external source capacitively coupled into Pin 17. The input at Pin 17 should be a sine wave with amplitude between 0.5 $V_{pp}$ and 1.0 $V_{pp}$.

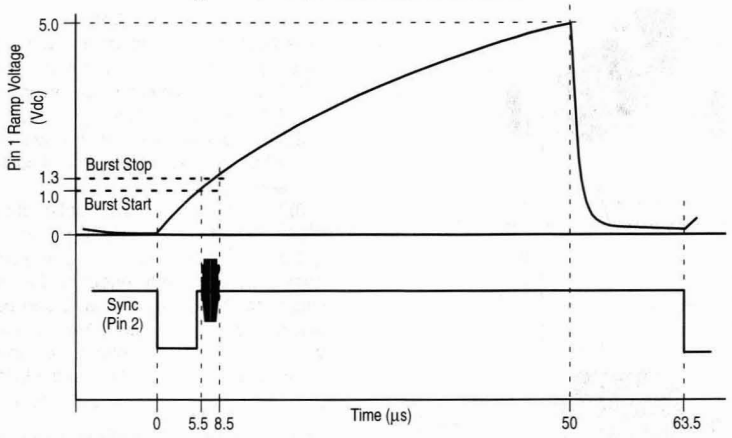
Also, it is possible to do both; i.e., let the oscillator "free run" on its own crystal and override with an external source. An extra coupling capacitor of 50 pF from the external source to Pin 17 was adequate with the experimentation attempted.

**Voltage Controlled 90°**

The oscillator drives the (B–Y) modulator and a voltage controlled phase shifter which produces an oscillator phase of 90° ± 5° at the (R–Y) modulator. In most situations, the result of an error of 5° is very subtle to all but the most expert eye. However, if it is necessary to adjust the angle to better accuracy, the circuit shown in Figure 11 can be used.

Pulling Pin 19 up will increase the (R–Y) to (B–Y) angle by about 0.25°/μA. Pulling Pin 19 down reduces the angle by the same sensitivity. The nominal Pin 19 voltage is about 6.3 V, so even though it is unregulated, the 12 V supply is best for good control. For effective adjustment, the simplest approach is to apply RGB color bar inputs and use a vectorscope. A simple bar generator giving R, G, and B outputs is shown in Figure 26.

**Figure 9. Ramp/Burst Gate Generator**




**Residual Feedthrough Components**

As shown in Figure 9(d), the composite output at Pin 9 for fully saturated color bars is about 2.6 $V_{pp}$, output with full chroma on the largest bars (cyan and red) being 1.7 $V_{pp}$. The typical device, due to imperfections in gain, matrixing, and modulator balance, will exhibit about 20 $mV_{pp}$ residual color subcarrier in both white and black. Both residuals can be reduced to less than 10 $mV_{pp}$ for the more exacting applications.

The subcarrier feedthrough in black is due primarily to imbalance in the modulators and can be nulled by sinking or sourcing small currents into clamp Pins 11 and 12 as shown in Figure 12. The nominal voltage on these pins is about 4.0 Vdc, so the 8.2 V regulator is capable of supplying a pull up source. Pulling Pin 11 down is in the 0° direction, pulling it up is towards 180°. Pulling Pin 12 down is in the 90° direction, pulling it up is towards 270°. Any direction of correction may be required from part to part.

White carrier imbalance at the output can only be corrected by juggling the relative levels of R, G, and B inputs for perfect balance. Standard devices are tested to be within 5% of balance at full saturation. Black balance should be adjusted first, because it affects all levels of gray scale equally. There is also usually some residual baseband video at the chroma output (Pin 13), which is most easily observed by disabling the color oscillator. Typical devices show 0.4 $V_{pp}$ of residual luminance for saturated color bar inputs. This is not a major problem since Pin 13 is always coupled to Pin 10 through a bandpass or a high pass filter, but it serves as a warning to pay proper attention to the coupling network.

**Figure 10. Adjusting Modulator Angle**

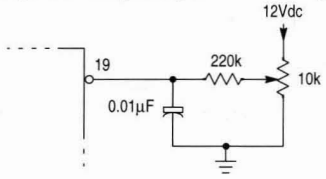


**Figure 11. Nulling Residual Color in Black**

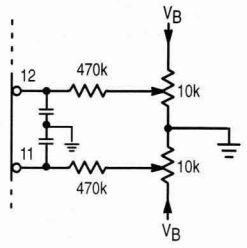
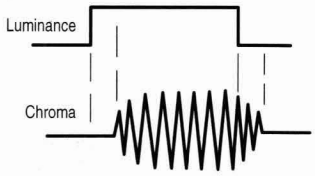



**Figure 12. Delay of Chroma Information**




### The Chroma Coupling Circuits

With the exception of S–VHS equipped monitors and receivers, it is generally true that most monitors and receivers have color IF 6.0 dB bandwidths limited to approximately ±0.5 MHz. It is therefore recommended that the encoder circuit should also limit the chroma bandwidth to approximately ±0.5 MHz through insertion of a bandpass circuit between Pin 13 and Pin 10. However, if S–VHS operation is desired, a coupling circuit which outputs the composite chroma directly for connection to a S–VHS terminal is given in the S–VHS application (see Figure 19).

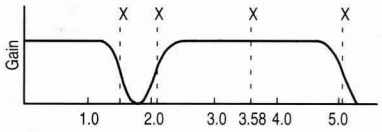
For proper color level in the video output, a ±0.5 MHz bandwidth and a midband insertion loss of 3.0 dB is desired. The bandpass circuit shown in Figure 7, using the TOKO fixed tuned transformer, couples Pin 10 to Pin 13 and gives this result. However, this circuit introduces about 350 ns of delay to the chroma information (see Figure 13). This must be accounted for in the luminance path.

A 350 ns delay results in a visible displacement of the color and black and white information on the final display. The solution is to place a delay line in the luminance path from Pins 6 to 8, to realign the two components. A normal TV receiver delay line can be used. These delay lines are usually of 1.0 kΩ to 1.5 kΩ characteristic impedance, and the resistors at Pins 6 and 8 should be selected accordingly. A very compact, lumped constant delay line is available from TDK (see Figure 25 for specifications). Some types of delay lines have very low impedances (approx. 100 Ω) and should not be used, due to drive and power dissipation requirements.

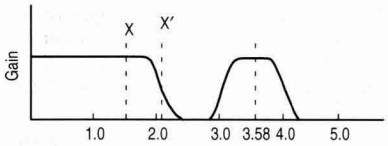
In the event of very low resolution RGB, the transformer and the delay line may be omitted from the circuit. Very low resolution for the MC1377 can be considered RGB information of less than 1.5 MHz. However, in this situation, a bandwidth reduction scheme is still recommended due to the response of most receivers.

Figure 14(a) shows the output of the MC1377 with low resolution RGB inputs. If no bandwidth reduction is employed then a monitor or receiver with frequency response shown in Figure 14(b), which is fairly typical of non–comb filtered monitors and receivers, will detect an incorrect luma sideband at X′. This will result in cross–talk in the form of chroma information in the luma channel. To avoid this situation, a simpler bandpass circuit as shown in Figure 15(a), can be used.

**Figure 13. MC1377 Output with Low Resolution RGB Inputs**




**(a) Encoder Output with Low Resolution Inputs and No Bandpass Transformer**




**(b) Standard Receiver Response**

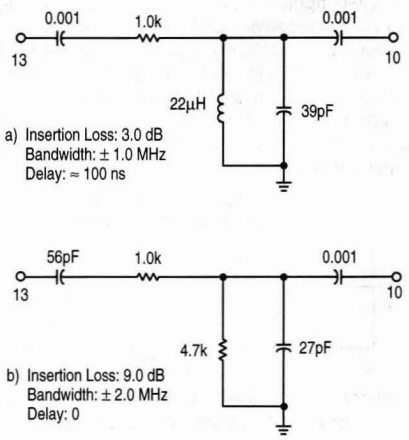
A final option is shown in Figure 15(b). This circuit provides very little bandwidth reduction, but enough to remove the chroma to luma feedthrough, with essentially no delay. There is, however, about a 9 dB insertion loss from this network.

It will be left to the designer to decide which, if any, compromises are acceptable. Color bars viewed on a good monitor can be used to judge acceptability of step luminance/chrominance alignment and step edge transients, but signals containing the finest detail to be encountered in the system must also be examined before settling on a compromise.

### The Output Stage

The output amplifier normally produces about 2.0 $V_{pp}$ and is intended to be loaded with 150 Ω as shown in Figure 16. This provides about 1.0 $V_{pp}$ into 75 Ω, an industry standard level (RS–343). In some cases, the input to the monitor may be through a large coupling capacitor. If so, it is necessary to connect a 150 Ω resistor from Pin 9 to ground to provide a low impedance path to discharge the capacitor. The nominal average voltage at Pin 9 is over 4.0 V. The 150 Ω dc load causes the current supply to rise another 30 mA (to approximately 60 mA total into Pin 14). Under this (normal) condition the total device dissipation is about 600 mW. The calculated worst case die temperature rise is 60°C, but the typical device in a test socket is only slightly warm to the touch at room temperature. The solid copper 20–pin lead frame in a printed circuit board will be even more effectively cooled.

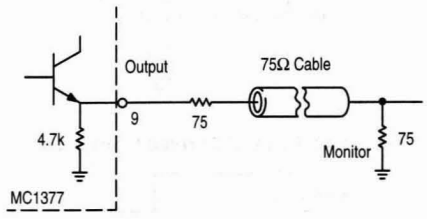
**Figure 14. Optional Chroma Coupling Circuits**




### Power Supplies

The MC1377 is designed to operate from an unregulated 10 V to 14 Vdc power supply. Device current into Pin 14 with open output is typically 35 mA. To provide a stable reference for the ramp generator and the video output, a high quality 8.2 V regulator can supply up to 10 mA for external uses, with an effective source impedance of less than 1.0 Ω. This regulator is convenient for a tracking dc reference for dc coupling the output to an RF modulator. Typical turn–on drift for the regulator is approximately –30 mV over 1 to 2 minutes in otherwise stable ambient conditions.

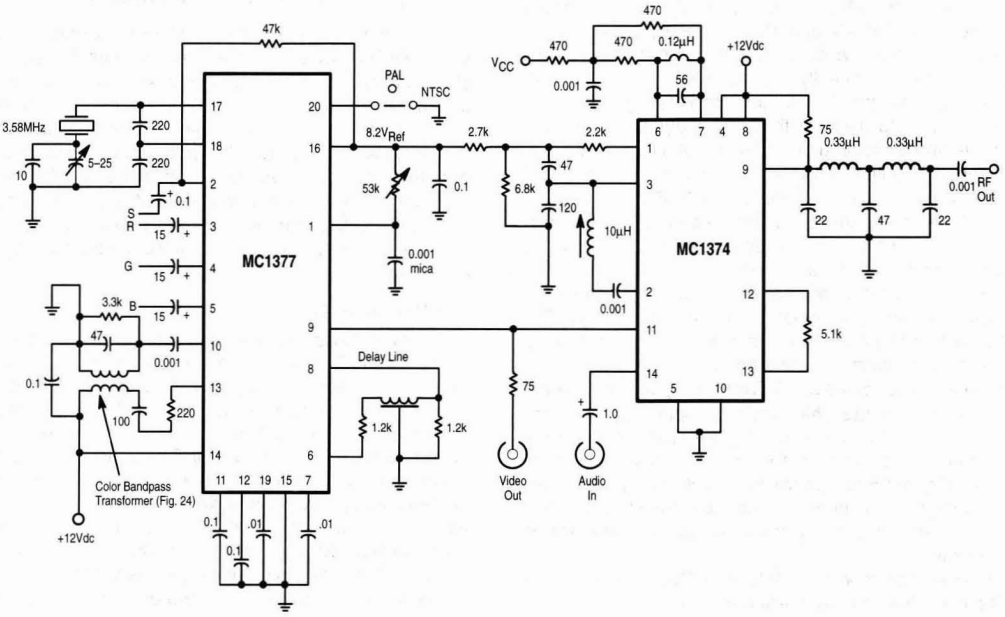
**Figure 15. Output Termination**




## SUMMARY

The preceding information was intended to detail the application and basis of circuit choices for the MC1377. A complete MC1377 application with the MC1374 VHF modulator is illustrated in Figure 17. The internal schematic diagram of the MC1377 is provided in Figure 8.

**Figure 16. Application with VHF Modulator**



## APPLICATIONS INFORMATION

### S–VHS

In full RGB systems (Figure 18), three information channels are provided from the signal source to the display to permit unimpaired image resolution. The detail reproduction of the system is limited only by the signal bandwidth and the capability of the color display device. Also, higher than normal sweep rates may be employed to add more lines within a vertical period and three separate projection picture tubes can be used to eliminate the "shadow mask" limitations of a conventional color CRT.

Figure 21 shows the "baseband" components of a studio NTSC signal. As in the previous example, energy is concentrated at multiples of the horizontal sweep frequency. The system is further refined by precisely locating the color subcarrier midway between luminance spectral components. This places all color spectra between luminance spectra and can be accomplished in the MC1377 only if "full interlaced" external color reference and sync are applied. The individual components of luminance and color can then be separated by the use of a comb filter in the monitor or receiver. This technique has not been widely used in consumer products, due to cost, but it is rapidly becoming less expensive and more common. Another technique which is gaining popularity is S–VHS (Super VHS).

In S–VHS, the chroma and luma information are contained on separate channels. This allows the bandwidth of both the chroma and luma channels to be as wide as the monitors ability to reproduce the extra high frequency information. An output coupling circuit for the composite chroma using the TOKO transformer is shown in Figure 19. It is composed of the bandpass transformer and an output buffer and has the frequency performance shown in Figure 20. The composite output (Pin 9) then produces the luma information as well as composite sync and blanking.

**Figure 17. Spectra of a Full RGB System**

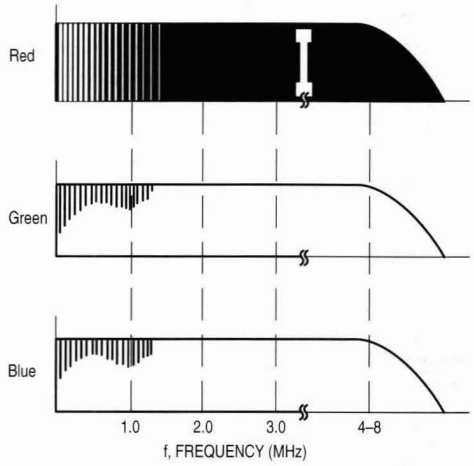
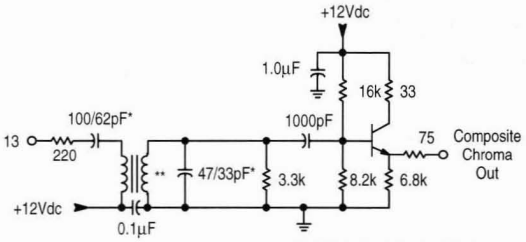
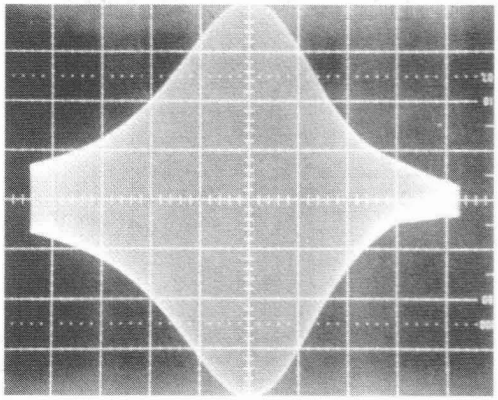


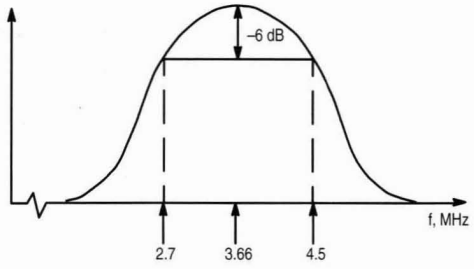

**Figure 18. S–VHS Output Buffer**




*Refers to different component values used for NTSC/PAL (3.58 MHz/4.43 MHz).
**Toko 166NNF–1026AG

**Figure 19. Frequency Response of Chroma Coupling Circuit**






9

### I/Q System versus (R–Y)/(B–Y) System

The NTSC standard calls for unequal bandwidths for I and Q (Figure 21). The MC1377 has no means of processing the unequal bandwidths because the I and Q axes are not used (Figure 22) and because the outputs of the (R–Y) and the (B–Y) modulators are added before being output at Pin 13. Therefore, any bandwidth reduction intended for the chroma information must be performed on the composite chroma information. This is generally not a problem, however, since most monitors compromise the standard quite a bit.

Figure 23 shows the typical response of most monitors and receivers. This figure shows that some crosstalk between luma and chroma information is always present. The acceptability of the situation is enhanced by the limited ability of the CRT to display information above 2.5 MHz. If the signal from the MC1377 is to be used primarily to drive conventional non–comb filtered monitors or receivers, it would be best to reduce the bandwidth at the MC1377 to that of Figure 23 to lessen crosstalk.

**Figure 20. NTSC Standard Spectral Content**

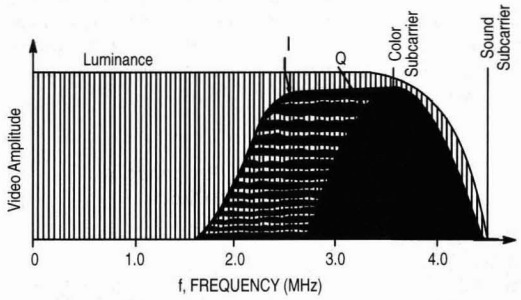



**Figure 21. Color Vector Relationship (Showing Standard Colors)**

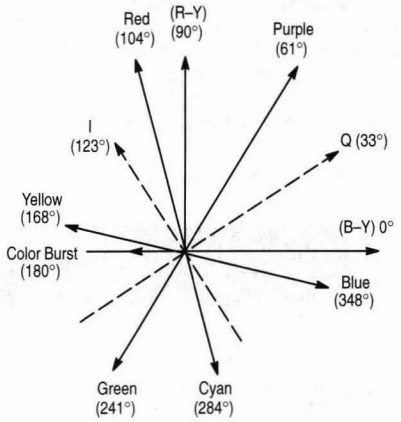



**Figure 22. Frequency Response of Typical Monitor/TV**

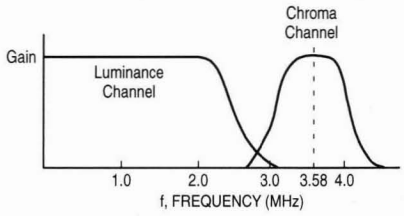
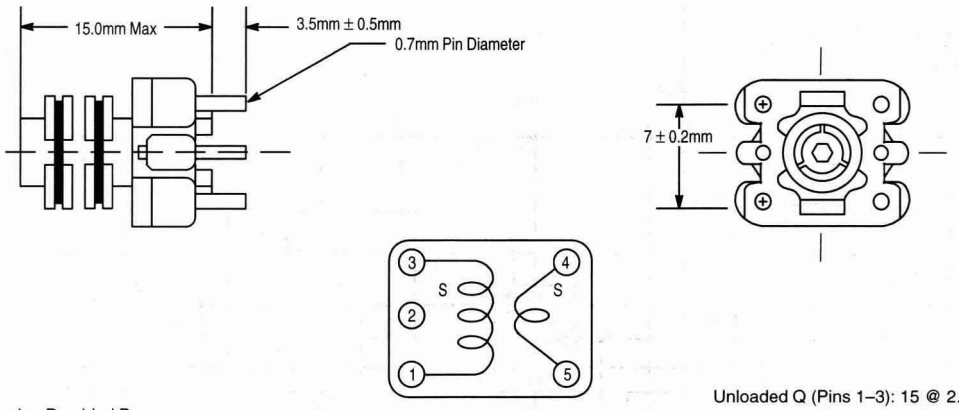


**Figure 23. A Prototype Chroma Bandpass Transformer**
**Toko Sample Number 166NNF–10264AG**

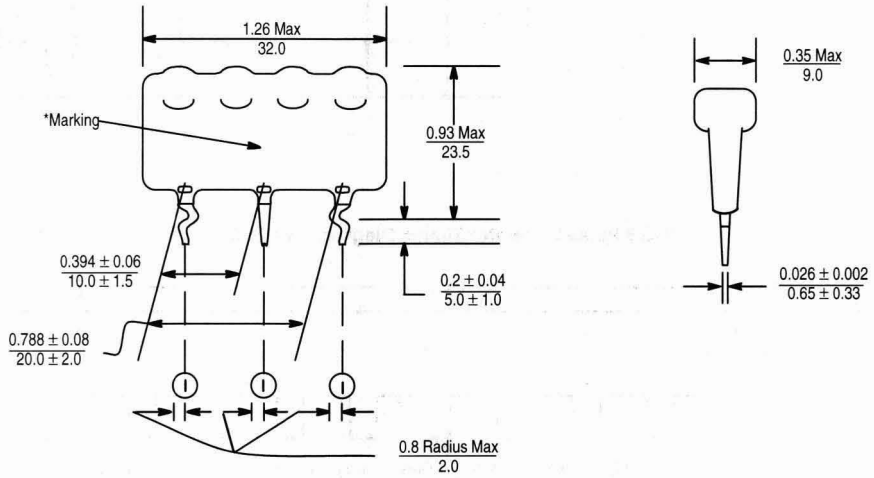



(Drawing Provided By:
Toko America, Skokie, IL)

**Connection Diagram**
**Bottom View**

Unloaded Q (Pins 1–3): 15 @ 2.5 MHz
Inductance: 30 µH ± 10% @ 2.5 MHz
Turns: 60 (each winding)
Wire: #38 AWG (0.1 m/m)

**Figure 24. A Prototype Delay Line**
**TDK Sample Number DL122301D–1533**

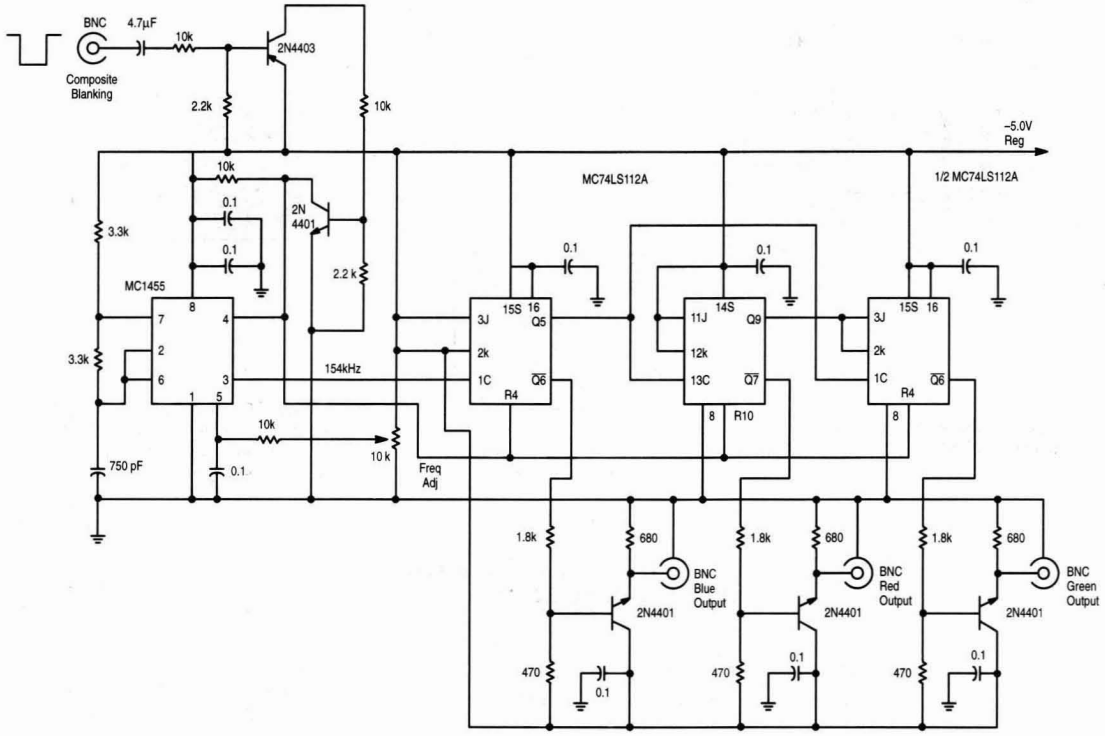



*Marking: Part Number, Manufacturer's Identification, Date Code and Lead Number.
Skokie, IL (TDK Corporation of America)

| Item | Specifications |
|---|---|
| Time Delay | 400 ns ± 10% |
| Impedance | 1200 Ω ± 10% |
| Resistance | Less Than 15 Ω |
| Transient Response with 20 ns Rise Time Input Pulse | Preshoot: 10% Max |
| | Overshoot: 10% Max |
| | Rise Time: 120 ns Max |
| Attenuation | 3 dB Max at 6.0 MHz |

9

**Figure 25. RGB Pulse Generator**




9

**RGB Pulse Generator Timing Diagram for NTSC**

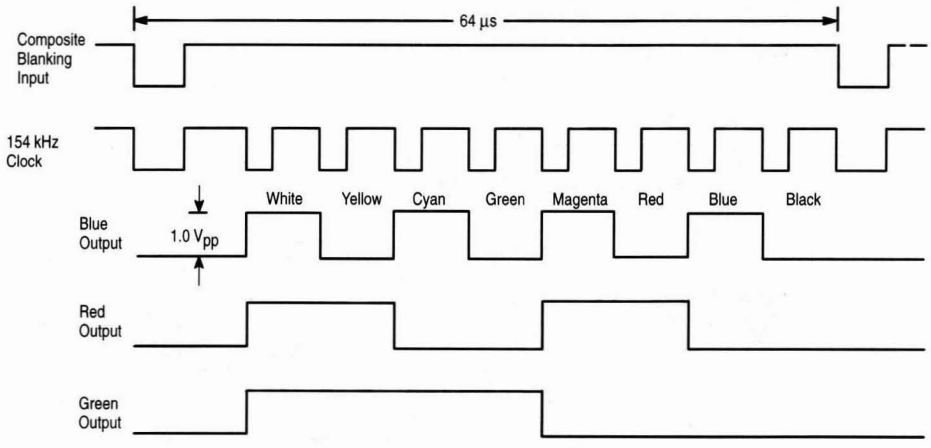
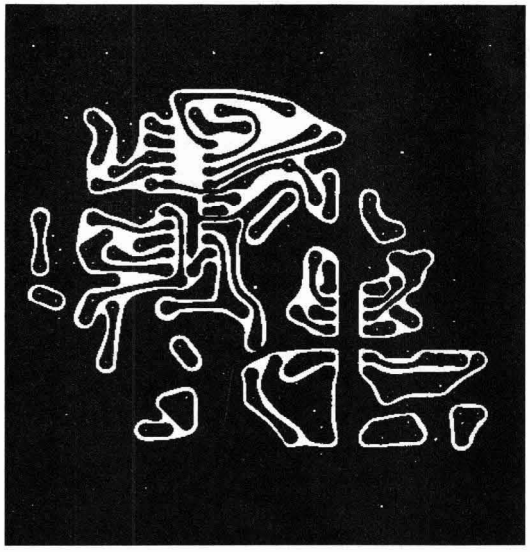
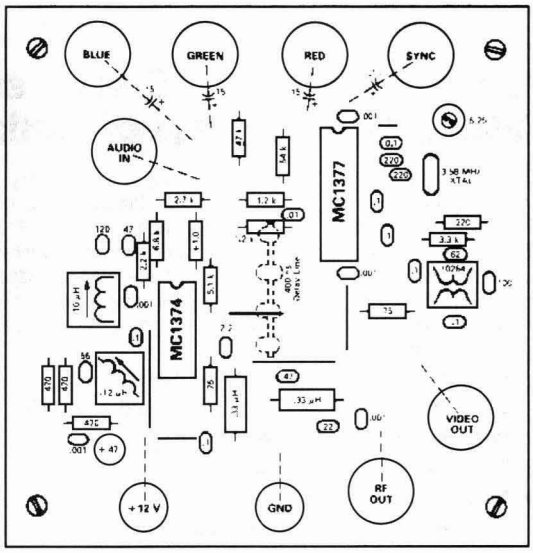


Figure 26. Printed Circuit Boards for the MC1377

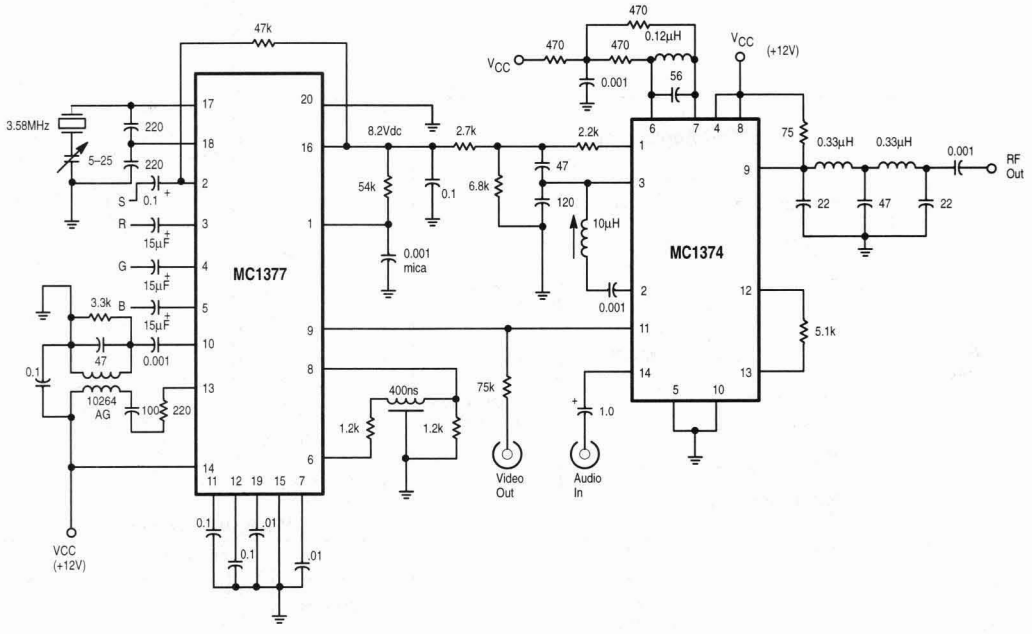


(CIRCUIT SIDE)




(COMPONENT SIZE)

Figure 27. Color TV Encoder – Modulator




9

MOTOROLA

# MC1378

# Color Television Composite Video Overlay Synchronizer

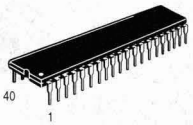
**COLOR TELEVISION COMPOSITE VIDEO OVERLAY SYNCHRONIZER**

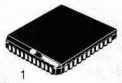
**SEMICONDUCTOR TECHNICAL DATA**

The MC1378 is a bipolar composite video overlay encoder and microcomputer synchronizer. The MC1378 contains the complete encoder function of the MC1377, i.e., quadrature color modulators, RGB matrix, and blanking level clamps, plus a complete complement of synchronizers to lock a microcomputer–based video source to any remote video source. The MC1378 can be used as a local system timing and encoding source, but it is most valuable when used to lock the microcomputer source to a remotely originated video signal.

- Contains All Needed Reference Oscillators
- Can Be Operated in PAL or NTSC Mode, 625 or 525 Line
- Wideband, Full–Fidelity Color Encoding
- Local or Remote Modes of Operation
- Minimal External Components
- Designed to Operate from 5.0 V supply
- Will Work with non standard Video

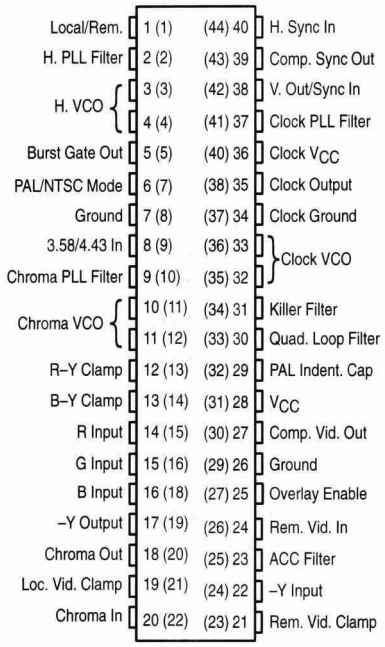
**P SUFFIX**
PLASTIC PACKAGE
CASE 711



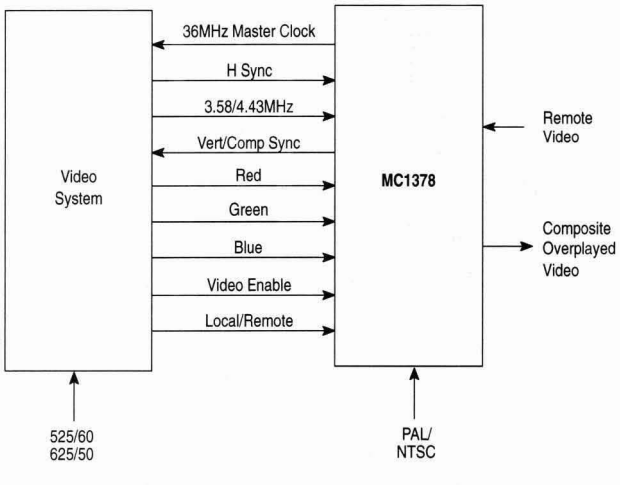

**FN SUFFIX**
PLASTIC PACKAGE
CASE 777
(PLCC–44)

**PIN CONNECTIONS**


Local/Rem. 1 (1)
H. PLL Filter 2 (2)
H. VCO 3 (3)
4 (4)
Burst Gate Out 5 (5)
PAL/NTSC Mode 6 (7)
Ground 7 (8)
3.58/4.43 In 8 (9)
Chroma PLL Filter 9 (10)
Chroma VCO 10 (11)
11 (12)
R–Y Clamp 12 (13)
B–Y Clamp 13 (14)
R Input 14 (15)
G Input 15 (16)
B Input 16 (18)
–Y Output 17 (19)
Chroma Out 18 (20)
Loc. Vid. Clamp 19 (21)
Chroma In 20 (22)
(44) 40 H. Sync In
(43) 39 Comp. Sync Out
(42) 38 V. Out/Sync In
(41) 37 Clock PLL Filter
(40) 36 Clock VCC
(38) 35 Clock Output
(37) 34 Clock Ground
(36) 33
(35) 32
Clock VCO
(34) 31 Killer Filter
(33) 30 Quad. Loop Filter
(32) 29 PAL Indent. Cap
(31) 28 VCC
(30) 27 Comp. Vid. Out
(29) 26 Ground
(27) 25 Overlay Enable
(26) 24 Rem. Vid. In
(25) 23 ACC Filter
(24) 22 –Y Input
(23) 21 Rem. Vid. Clamp

* ( ) PLCC Pin Assignments

**Figure 1. Simplified Application**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1378P | $T_A$ = 0° to +70°C | Plastic DIP |
| MC1378FN | | PLCC–44 |

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## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 6.0 | Vdc |
| Operating Temperature | $T_A$ | 0 to +70 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Power Dissipation, Package<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

## RECOMMENDED OPERATING CONDITIONS

| Condition | Pin | Value | Unit |
|---|---|---|---|
| Supply Voltage | 28, 36 | 5.4 ± 0.25 | Vdc |
| RGB Input for 100% Saturation | 14, 15, 16 | 1.0 | Vpp |
| Color Oscillator Input Level | 8 | 0.5 | Vpp |
| Video Input, Positive | 24 | 1.0 | Vpp |

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 5.0 V, $T_A$ = 25°C, circuit of Figure 4 or 5)

| Characteristics | | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Supply Current | | 28, 36 | – | 100 | – | mAdc |
| Video Output, Open Circuit, Positive | | 27 | – | 2.0 | 9.4 | $V_{pp}$ |
| Modulation Angle (R – Y) to (B – Y) | | – | 87 | 90 | 93 | Degrees |
| RGB Input Impedance | | 14, 15, 16 | – | 10 | – | kΩ |
| Local/Remote Switch (TTL) | High<br>Low | 1 | – | Remote<br>Local | – | – |
| Horizontal Sync Input, Negative Going | (TTL) | 40 | – | 4.3 | – | $V_{pp}$ |
| Vertical Sync Output, Negative Going, Remote Mode | (TTL) | 38 | – | 4.3 | – | $V_{pp}$ |
| Composite Sync Output, Negative Going | (TTL) | 39 | – | 4.3 | – | $V_{pp}$ |
| Burst Gate Output, Positive Going | (TTL) | 5 | – | 4.3 | – | $V_{pp}$ |

**Description of Operation** – Refer to Figures 3, 4

| Remote Mode | Local Mode |
|---|---|
| The incoming remote video signal (Pin 24) supplies all synchronizing information. A discussion of the function of the phase detectors helps to clarify the lockup method:<br><br>PD1 — locks the internally counted–down 4 MHz horizontal VCO to the incoming horizontal sync. It is fast acting, to follow VCR source fluctuations.<br><br>PD2 — locks the 36 MHz clock VCO, which is divided down by the video system, to the divided down horizontal VCO.<br><br>PD3 — is a gated phase detector which locks the 14 MHz crystal oscillator, divided by 4, to the incoming color burst.<br><br>PD4 — controls an internal phase shifter to assure that the outgoing color burst is the same phase as incoming burst at PD3.<br>PD5 — not used in REMOTE MODE | The MC1378 and a video system combine to provide a fully synchronized standard signal source. In this case, composite sync must be supplied by the video system or other time base system. In the MC1378 the phase detectors operate as follows:<br><br>PD1 — locks the internally counted–down 4 MHz horizontal VCO to a Horizontal Sync signal (at Pin 40) from the video system (counted down from 36 MHz)<br><br>PD2 — not used in LOCAL MODE.<br>PD3 — not used in LOCAL MODE.<br><br>PD4 — active, but providing an arbitrary phase shift setting between the color oscillator and the output burst phase.<br><br>PD5 — locks the 36 MHz clock VCO (which is divided down by the video system) to the 14 MHz (crystal) color oscillator. The 14 MHz is, therefore, the system standard in LOCAL MODE, and is not DC controlled. |
| Vertical lock is obtained by continuously resetting the sync generator in the video system with separated vertical sync from the MC1378, Pin 38. This signal is TTL level vertical block sync, negative going. The horizontal sync from the video system to Pin 40 is also TTL level with sync negative going. The local/remote switch, Pin 1, is in local mode when grounded, remote mode when taken to 5.0 V. The overlay control, Pin 25, has an analog characteristic, centered about 1.0 V, which allows fading from local to remote. | **COMPOSITE VIDEO GENERATION**<br>The color encoding at the RGB signals is done exactly as in the MC1377. Composite chroma is looped out at Pins 18 and 20 to allow the designer to choose band shaping. Luminance is similarly brought out (Pins 17 and 22) to permit installation of the appropriate delay.<br>Composite sync output, Pin 39, and burst gate output, Pin 5, are provided for convenience only. |

9

**Figure 2. Representative Block Diagram**

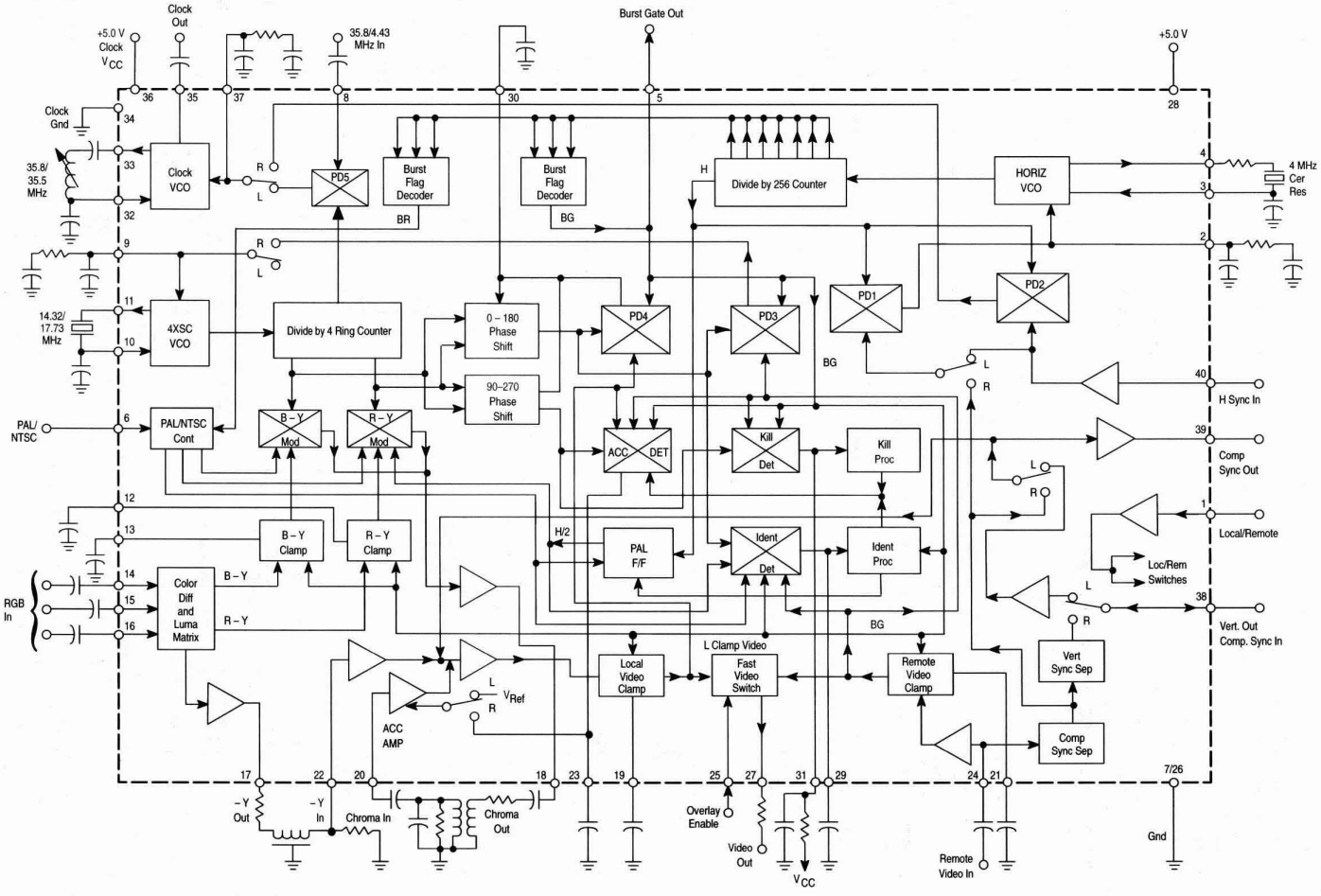


**Figure 3. Remote Mode**

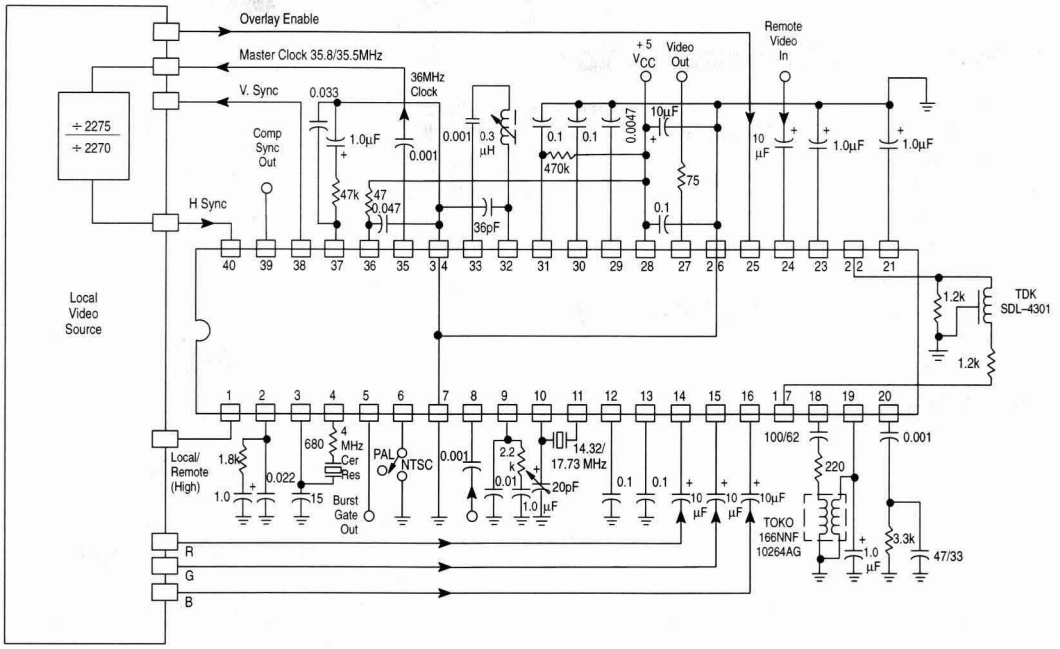
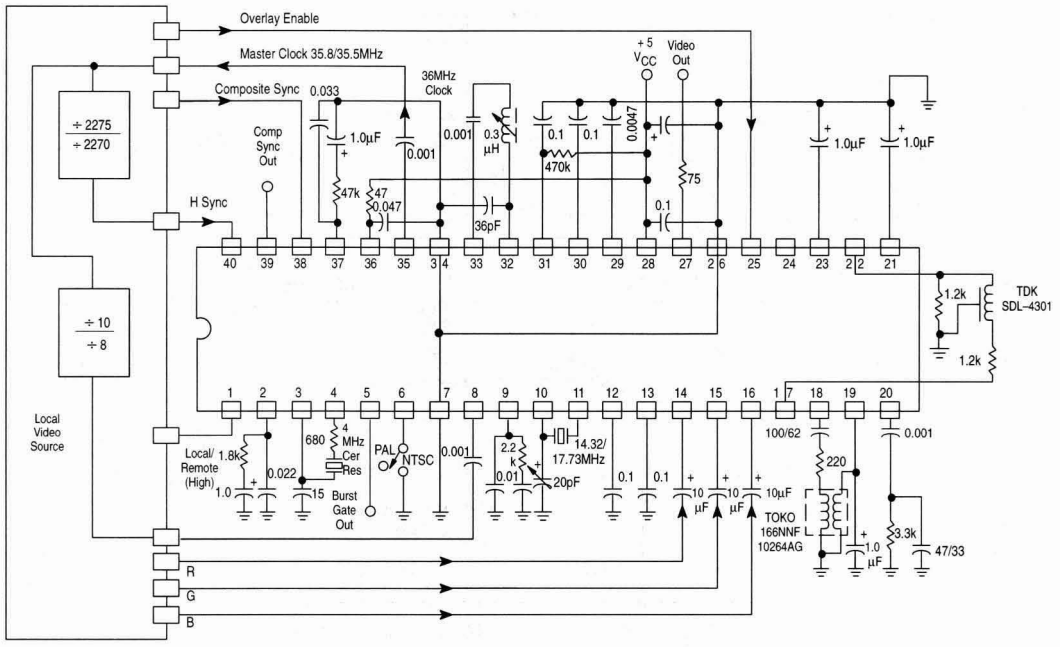



**Figure 4. Local Mode**



MOTOROLA

# MC1391

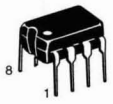
# TV Horizontal Processor

The MC1391 provides low–level horizontal sections including phase detector, oscillator and pre–driver. This device was designed for use in all types of television receivers.

- Internal Shunt Regulator
- Preset Hold Control Capability
- ±300 Hz Typical Pull–In
- Linear Balanced Phase Detector
- Variable Output Duty Cycle for Driving Tube or Transistor
- Low Thermal Frequency Drift
- Small Static Phase Error
- Adjustable DC Loop Gain
- Positive Flyback Inputs

**TV HORIZONTAL PROCESSOR**

**SEMICONDUCTOR TECHNICAL DATA**

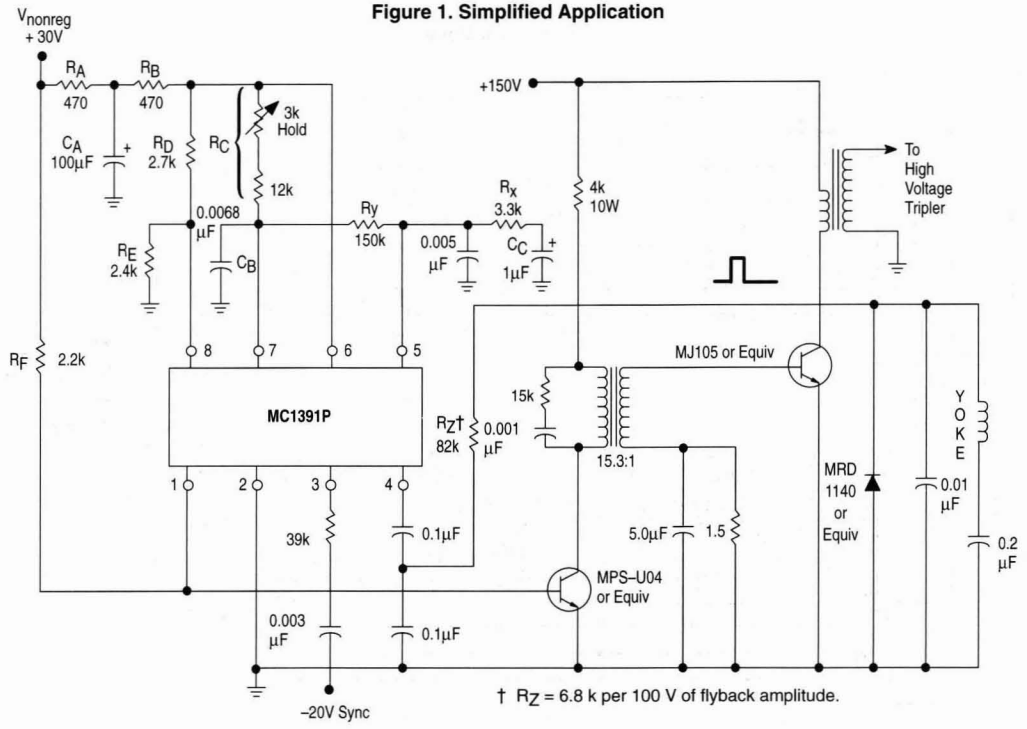



**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1391P | $T_A$ = 0° to +70°C | Plastic DIP |

**Figure 1. Simplified Application**




This circuit has an oscillator pull–in range of ±300 Hz, a noise bandwidth of 320 Hz, and a damping factor of 0.8.

**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Value | Unit |
|---|---|---|
| Supply Current | 40 | mAdc |
| Output Voltage | 40 | Vdc |
| Output Current | 30 | mAdc |
| Sync Input Voltage (Pin 3) | 5.0 | $V_{pp}$ |
| Flyback Input Voltage (Pin 4) | 5.0 | $V_{pp}$ |
| Power Dissipation (Package Limitation)<br>Plastic Package<br>Derate above $T_A$ = +25°C | <br>625<br>5.0 | <br>mW<br>mW/°C |
| Operating Temperature Range (Ambient) | 0 to +70 | °C |
| Storage Temperature Range | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = +25°C, unless otherwise noted. See Test Circuit of Figure 2, all switches in position 1.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Regulated Voltage (Pin 6) | 8.0 | 8.6 | 9.4 | Vdc |
| Supply Current (Pin 6) | – | 20 | – | mAdc |
| Collector–Emitter Saturation Voltage (Output Transistor Q1 in Figure 6)<br>($I_C$ = 20 mA, Pin 1 ) Vdc | – | 0.15 | 0.25 | Vdc |
| Voltage (Pin 4) | – | 2.0 | – | Vdc |
| Oscillator Pull–in Range (Adjust $R_H$ in Figure 2) | – | ±300 | – | Hz |
| Oscillator Hold–in Range (Adjust $R_H$ in Figure 2) | – | ±900 | – | Hz |
| Static Phase Error<br>(Δf = 300 Hz) | – | 0.5 | – | µs |
| Free–running Frequency Supply Dependance<br>(S1 in position 2) | – | ±3.0 | – | Hz/Vdc |
| Phase Detector Leakage (Pin 5)<br>(All switches in position 2) | – | – | ±1.0 | µA |
| Sync Input Voltage (Pin 3) | 2.0 | – | 5.0 | $V_{pp}$ |
| Sawtooth Input Voltage (Pin 4) | 1.0 | – | 3.0 | $V_{pp}$ |

9

**Figure 2. Test Circuit**

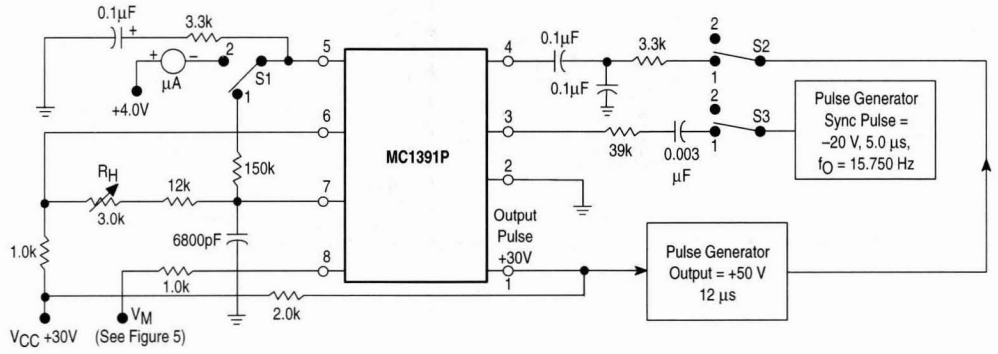


**Figure 3. Frequency versus Temperature**

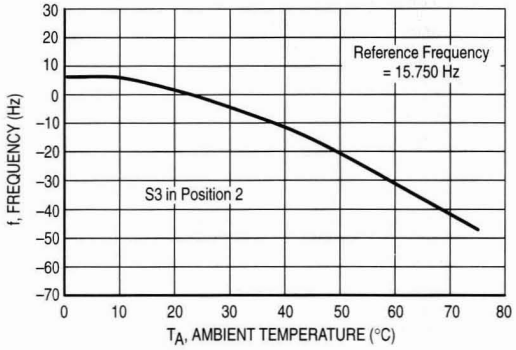



**Figure 4. Frequency Drift versus Warm–Up Time**

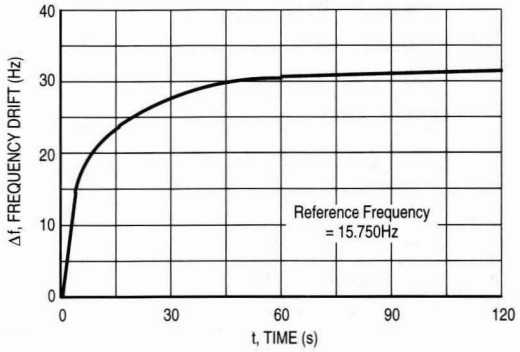



**Figure 5. Mark Space Ratio**

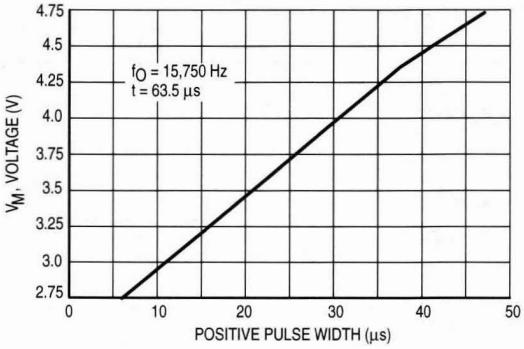



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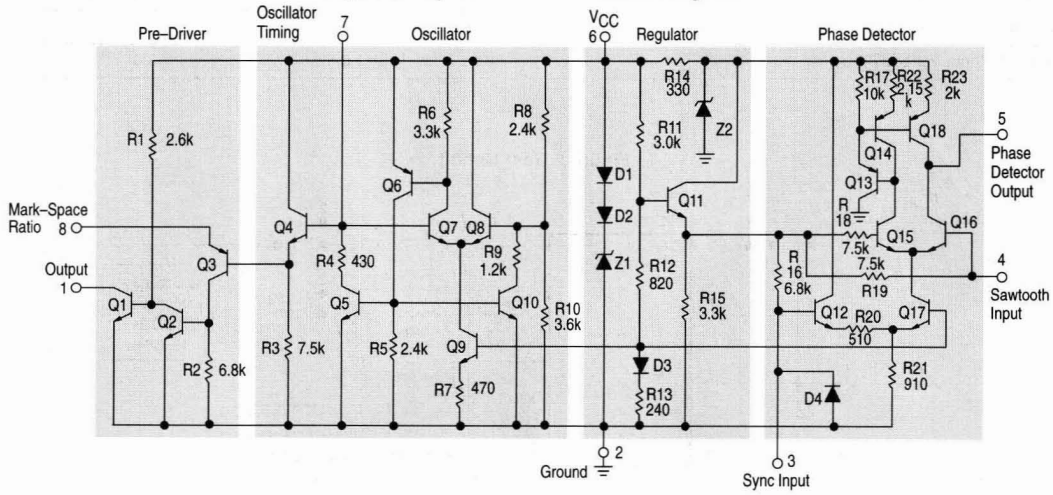
**Figure 6. Representative Schematic Diagram**



## CIRCUIT OPERATION

The MC1391P contains the oscillator, phase detector and predriver sections needed for a television horizontal APC loop.

The oscillator is an RC type with one pin (Pin 7) used to control the timing. The basic operation can be explained easily. If it is assumed that Q7 is initially off, then the capacitor connected from Pin 7 to ground will be charged by an external resistor ($R_C$) connected to Pin 6. As soon as the voltage at Pin 7 exceeds the potential set at the base of Q8 by resistors R8 and R10, Q7 will turn on and Q6 will supply base current to Q5 and Q10. Transistor Q10 will set a new, lower potential at the base of Q8 determined by R8, R9 and R10. At the same time, transistor Q5 will discharge the capacitor through R4 until the base bias of Q7 falls below that of Q8, at which time Q7 will turn off and the cycle repeats.

The sawtooth generated at the base of Q4 will appear across R3 and turn off Q3 whenever it exceeds the bias set on Pin 8. By adjusting the potential at Pin 8, the duty cycle (MSR) at the predriver output pin (Pin 1) can be changed to accommodate either tube or transistor horizontal output stages.

The phase detector is isolated from the remainder of the circuit by R14 and Z2. The phase detector consists of the comparator Q15, Q16 and the gated current source Q17. Negative going sync pulses at Pin 3 turn off Q12 and the current division between Q15 and Q16 will be determined by the phase relationship of the sync and the sawtooth waveform at Pin 4, which is derived from the horizontal flyback pulse. If there is no phase difference between the sync and sawtooth, equal currents will flow in the collectors of Q15 and Q16 each of half the sync pulse period. The current in Q15 is turned around by Q18 so that there is no net output current at Pin 5 for balanced conditions. When a phase offset occurs, current will flow either in or out of Pin 5. This pin is connected via an external low–pass filter to Pin 7, thus controlling the oscillator.

Shunt regulation for the circuit is obtained with a zero temperature coefficient from the series combination of D1, D2 and Z1.

## APPLICATION INFORMATION

Although it is an integrated circuit, the MC1391P has all the flexibility of a conventional discrete component horizontal APC loop. The internal temperature compensated voltage regulator allows a wide supply voltage variation to be tolerated, enabling operation from nonregulated power supplies. A minimum value for supply current into Pin 6 to maintain zener regulation is about 18 mA. Allowing 2.0 mA for the external dividers

$$R_A + R_B = \frac{V_{nonreg(min)} - 8.8}{20 \times 10^{-3}}$$

Components $R_A$, $R_B$ and $C_A$ are used for ripple rejection. If the supply voltage ripple is expected to be less than 100 mV (for a 30 V supply) then $R_A$ and $R_B$ can be combined and $C_A$ omitted.

The output pulse width can be varied from 6.0 µs to 48 µs by changing the voltage at Pin 8 (see Figure 5). However, care should be taken to keep the lead lengths to Pin 8 as short as possible at Pin 1. The parallel impedance of $R_D$ and $R_E$ should be close to 1.0 kΩ to ensure stable pulse widths. For 15 mA drive at saturation

$$R_F = \frac{V_{nonreg} - 0.3}{15 \times 10^{-3}}$$

The oscillator free–running frequency is set by $R_C$ and $C_B$ connected to Pin 7. For values of $R_C \geq R_{discharge}$ (R4 in Figure 6), a useful approximation for the free–running frequency is

$$f_O = \frac{1}{0.6\, R_C C_B}$$

Proper choice of $R_C$ and $C_B$ will give a wide range of oscillator frequencies – operation at 31.5 kHz for countdown circuits is possible for example. As long as the product $R_C C_B \approx 10^{-4}$ many combinations of values of $R_C$ and $C_B$ will satisfy the free–running frequency requirement of 15.734 kHz. However, the sensitivity of the oscillator (β) to control–current from the phase detector is directly dependent on the magnitude of $R_C$, and this provides a convenient method of adjusting the dc loop gain (fc).

For a given phase detector sensitivity (µ) = $1.60 \times 10^{-4}$ A/rad

$$f_c = \mu\beta \text{ and } \beta = 3.15 \times R_C \text{ Hz/mA}$$

Increasing $R_C$ will raise the dc loop gain and reduce the static phase error (S.P.E.) for a given frequency offset. Secondary effects are to increase the natural resonant frequency of the loop ($\omega_n$) and give a wider pull–in range from an out–of–lock condition. The loop will also tend to be underdamped with fast pull–in times, producing good airplane flutter performance. However, as the loop becomes more underdamped impulse noise can cause shock excitation of the loop. Unlimited increase in the dc loop gain will also raise the noise bandwidth excessively causing horizontal jitter with thermal noise. Once the dc loop gain has been selected for adequate SPE performance, the loop filter can be used to produce the balance between other desirable characteristics. Damping of the loop is achieved most directly by changing the resistor $R_X$ with respect to $R_Y$ which modifies the ac/dc gain ration (m) of the loop. Lowering this ratio will reduce the pull–in range and noise bandwidth (fnn). (Note: very large values of $R_Y$ will limit the control capability of the phase detector with a corresponding reduction in hold–in range.)

Static phasing can be adjusted simply by adding a small resistor between the flyback pulse integrating capacitor and ground. The sync coupling capacitor should not be too small or it can charge during the vertical pulse and this may result in picture bends at the top of the CRT.

Note: In adjusting the loop parameters, the following equations may prove useful:

$$f_{nn} = \frac{1 \times \chi^2\, T\omega_C}{4\chi T} \qquad \chi = \frac{R_X}{R_Y}$$

$$w_n = \sqrt{\frac{\omega_C}{(1 + c)T}} \qquad \omega_C = 2\pi f_c$$

$$T = R_Y C C$$

$$K = \frac{\chi^2 T\omega_C}{4}$$

where: K = loop damping coeffecient

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MOTOROLA

# MC3340

# Electronic Attenuator

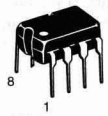
The MC3340 is a simple but very effective electronic attenuator. This device offers up to 80 dB of attenuation control for frequencies to 1.0 MHz. THD (distortion) is less than 1% – up to 15 dB attenuation and less than 3% – up to 40 dB.

Typical uses include instrumentation control, remote control audio amplifiers, electronic games, and CATV (cable TV) set–top converter audio control.

- Designed for use in:
  - DC Operated Volume Control
  - Compression and Expansion Amplifier Applications
- Controlled by DC Voltage or External Variable Resistor
- Economical 8–Pin Dual–In–Line Package

**ELECTRONIC ATTENUATOR**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

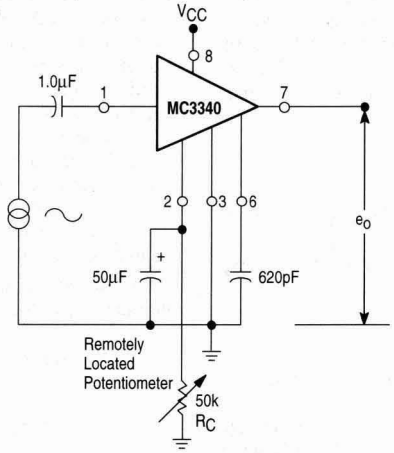
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 20 | Vdc |
| Power Dissipation @ $T_A$ = 25°C<br>Derate above $T_A$ = 25°C | $P_D$ | 1.2<br>10 | W<br>mW/°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to +75 | °C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3340P | $T_A$ = 0° to +75°C | Plastic DIP |

9

**Figure 1. Typical DC Remote Volume Control**



**ELECTRICAL CHARACTERISTICS** ($e_{in}$ = 100 mVrms, f = 1.0 kHz, $V_{CC}$ = 16 Vdc, $T_A$ = +25°C, unless otherwise noted.)

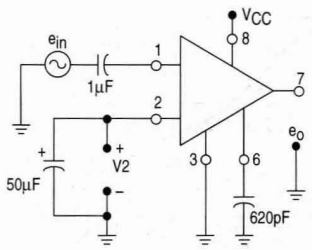
| Circuit | Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
|  | Operating Power Supply Voltage | 0.8 | – | 18 | Vdc |
| | Control Terminal Sink Current, Pin 2 ($e_{in}$ = 0) | – | – | 2.0 | mAdc |
| | Maximum Input Voltage | – | – | 0.5 | Vrms |
| | Voltage Gain | 11 | 13 | – | dB |
| | Attenuation Range from Maximum Gain (V2 = 6.5 Vdc) | 70 | 80 | – | dB |
| | Total Harmonic Distortion (Pin 2 Gnd) ($e_{in}$ = 100 mVrms, $e_o = A_V \cdot e_{in}$) | – | 0.6 | 1.0 | % |



**Figure 2. Representative Schematic Diagram**

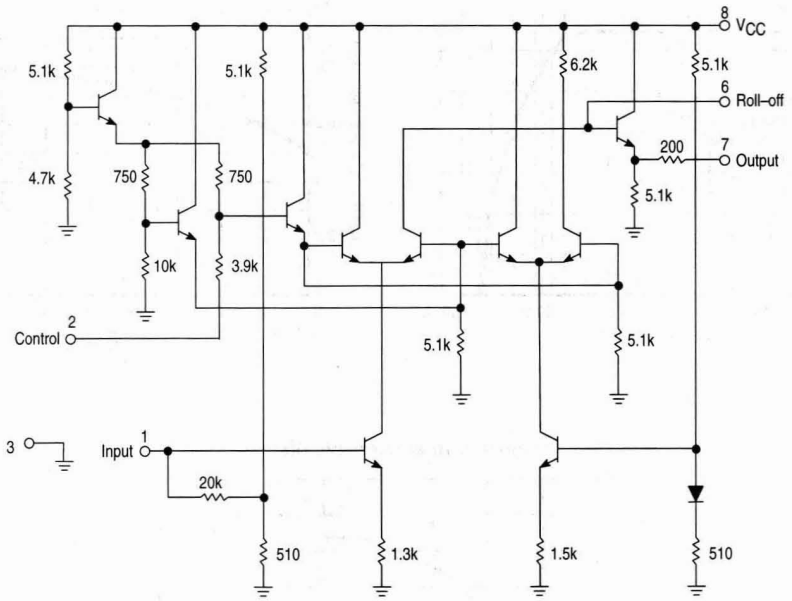


**Figure 3. Attenuation versus DC Control Voltage**

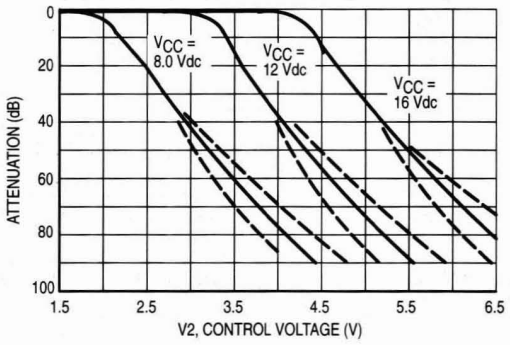



**Figure 4. Attenuation versus Control Resistor**

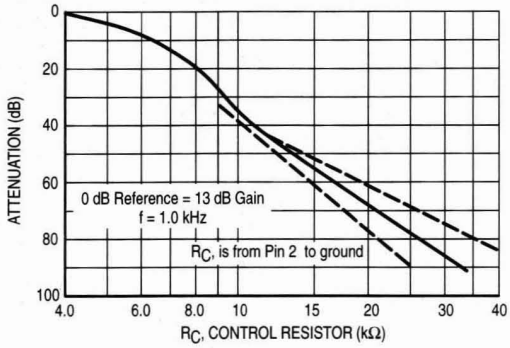



**Figure 5. Frequency Response**

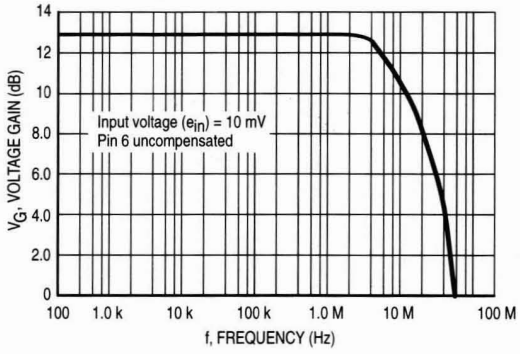



**Figure 6. Output Voltage Swing**

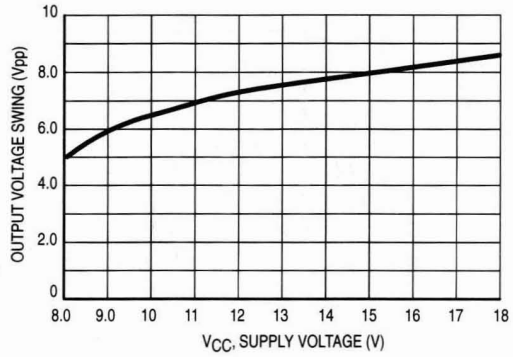
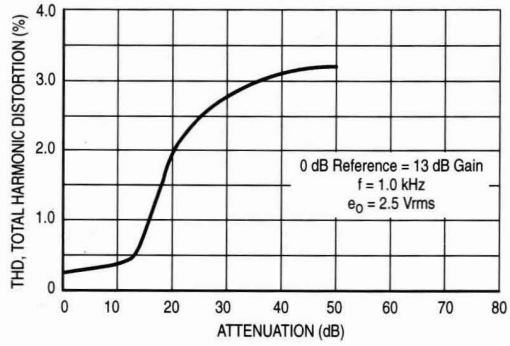



**Figure 7. Total Harmonic Distortion**



MOTOROLA

# MC3346

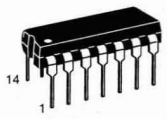
# General Purpose Transistor Array One Differentially Connected Pair and Three Isolated Transistor Arrays

**GENERAL PURPOSE TRANSISTOR ARRAY**

**SEMICONDUCTOR TECHNICAL DATA**

The MC3346 is designed for general purpose, low power applications for consumer and industrial designs.

- Guaranteed Base–Emitter Voltage Matching
- Operating Current Range Specified: 10 μA to 10 mA
- Five General Purpose Transistors in One Package




**P SUFFIX**
PLASTIC PACKAGE
CASE 646

**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

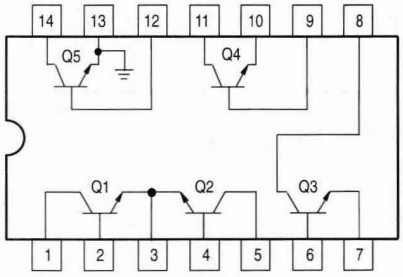
**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector–Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector–Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Emitter–Base Voltage | $V_{EB}$ | 5.0 | Vdc |
| Collector–Substrate Voltage | $V_{CIO}$ | 20 | Vdc |
| Collector Current – Continuous | $I_C$ | 50 | mAdc |
| Total Power Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 1.2<br>10 | W<br>mW/°C |
| Operating Temperature Range | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3346D | $T_A$ = –40° to +85°C | SO–14 |
| MC3356P | | Plastic DIP |

**PIN CONNECTIONS**




Pin 13 is connected to substrate and must remain at the lowest circuit potential.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = +25°C, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **STATIC CHARACTERISTICS** | | | | | |
| Collector–Base Breakdown Voltage ($I_C$ = 10 μAdc) | $V_{(BR)CBO}$ | 20 | 60 | – | Vdc |
| Collector–Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc) | $V_{(BR)CEO}$ | 15 | – | – | Vdc |
| Collector–Substrate Breakdown Voltage ($I_C$ = 10 μA) | $V_{(BR)CIO}$ | 20 | 60 | – | Vdc |
| Emitter–Base Breakdown Voltage ($I_E$ = 10 μAdc) | $V_{(BR)EBO}$ | 5.0 | 7.0 | – | Vdc |
| Collector–Base Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 40 | nAdc |
| DC Current Gain<br>($I_C$ = 10 mAdc, $V_{CE}$ = 3.0 Vdc)<br>($I_C$ = 1.0 mAdc, $V_{CE}$ = 3.0 Vdc)<br>($I_C$ = 10 μAdc, $V_{CE}$ = 3.0 Vdc) | $h_{FE}$ | <br>–<br>40<br>– | <br>140<br>130<br>60 | <br>–<br>–<br>– | – |
| Base–Emitter Voltage<br>($V_{CE}$ = 3.0 Vdc, $I_E$ = 1.0 mAdc)<br>($V_{CE}$ = 3.0 Vdc, $I_E$ = 10 mAdc) | $V_{BE}$ | <br>–<br>– | <br>0.72<br>0.8 | <br>–<br>– | Vdc |
| Input Offset Current for Matched Pair Q1 and Q2 ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | $\lvert I_{IO1} - I_{IO2} \rvert$ | – | 0.3 | 2.0 | μAdc |
| Magnitude of Input Offset Voltage ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | – | – | 0.5 | 5.0 | mVdc |
| Temperature Coefficient of Base–Emitter Voltage ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | $\frac{\Delta V_{BE}}{D_T}$ | – | –1.9 | – | mV/°C |
| Temperature Coefficient | $\frac{\lvert \Delta V_{IO} \rvert}{D_T}$ | – | 1.0 | – | μV/°C |
| Collector–Emitter Cutoff Current ($V_{CE}$ = 10 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 0.5 | μAdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Low Frequency Noise Figure ($V_{CE}$ = 3.0 Vdc, $I_C$ = 100 μAdc, $R_S$ = 1.0 kΩ, f = 1.0 kHz) | NF | – | 3.25 | – | dB |
| Forward Current Transfer Ratio ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 kHz) | $h_{FE}$ | – | 110 | – | – |
| Short Circuit Input Impedance ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | $h_{ie}$ | – | 3.5 | – | kΩ |
| Open Circuit Output Impedance ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | $h_{oe}$ | – | 15.6 | – | μmhos |
| Reverse Voltage Transfer Ratio ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc) | $h_{re}$ | – | 1.8 | – | $x10^{-4}$ |
| Forward Transfer Admittance ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 MHz) | $y_{fe}$ | – | 31–j1.5 | – | – |
| Input Admittance ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 MHz) | $y_{ie}$ | – | 0.3 + j0.04 | – | – |
| Output Admittance ($V_{CE}$ = 3.0 Vdc, $I_C$ = 1.0 mAdc, f = 1.0 MHz) | $y_{oe}$ | – | 0.001 + j0.03 | – | – |
| Current–Gain – Bandwidth Product ($V_{CE}$ = 3.0 Vdc, $I_C$ = 3.0 mAdc) | $f_T$ | 300 | 550 | – | MHz |
| Emitter–Base Capacitance ($V_{EB}$ = 3.0 Vdc, $I_E$ = 0) | $C_{eb}$ | – | 0.6 | – | pF |
| Collector–Base Capacitance ($V_{CB}$ = 3.0 Vdc, $I_C$ = 0) | $C_{cb}$ | – | 0.58 | – | pF |
| Collector–Substrate Capacitance ($V_{CS}$ = 3.0 Vdc, $I_C$ = 0) | $C_{CI}$ | – | 2.8 | – | pF |

**Figure 1. Collector Cutoff Current versus Temperature (Each Transistor)**

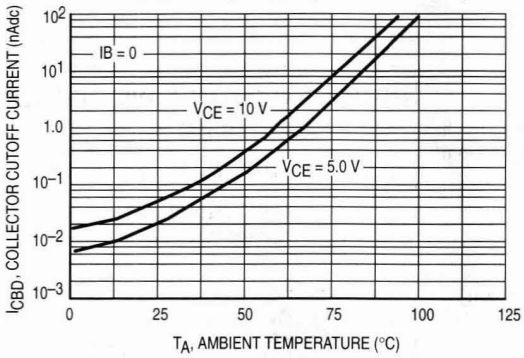



**Figure 2. Collector Cutoff Current versus Temperature (Each Transistor)**

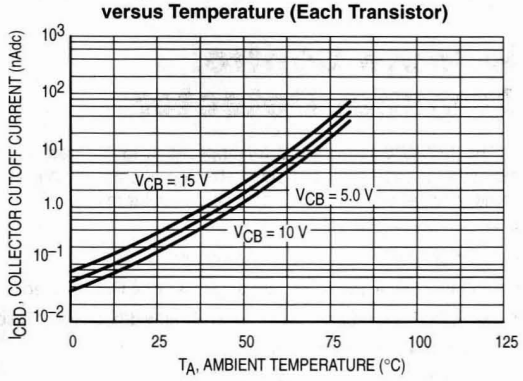



**Figure 3. Input Offset Characteristics for Q1 and Q2**

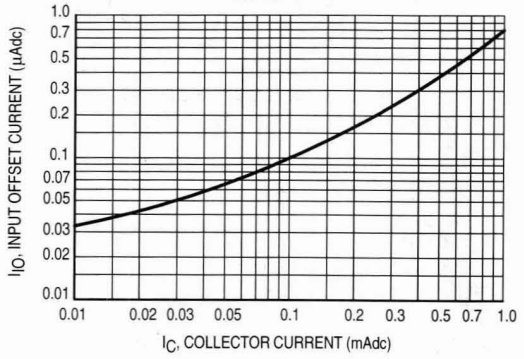



**Figure 4. Base–Emitter and Input Offset Voltage Characteristics**

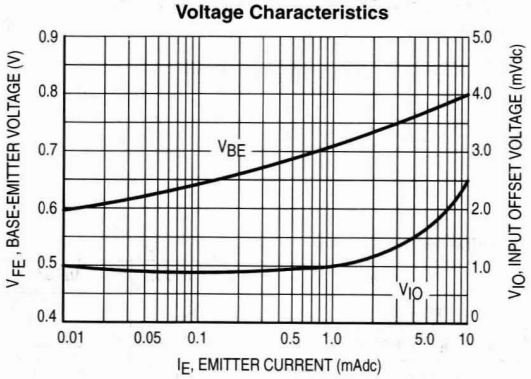
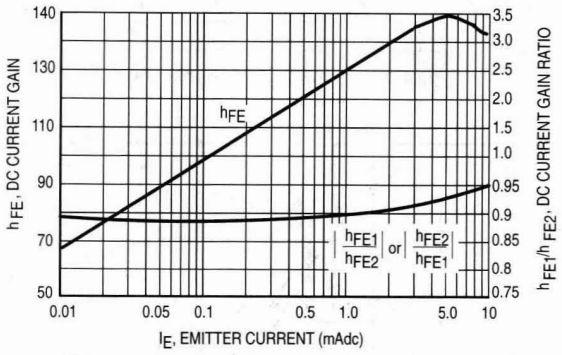



**Figure 5. DC Current Gain**

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MOTOROLA

# MC3373

# Remote Control Amplifier/Detector

**REMOTE CONTROL WIDEBAND AMPLIFIER WITH DETECTOR**

**SEMICONDUCTOR TECHNICAL DATA**

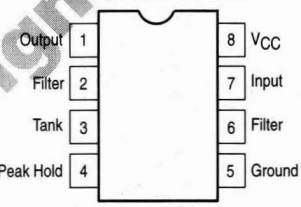
The MC3373 is intended for application in infrared remote controls. It provides the high gain and pulse shaping needed to couple the signal from an IR receiver diode to the tuning control system logic.

- High Gain Pre–Amp
- Envelope Detector for PCM Demodulation
- Simple Interface to Microcomputer Remote Control Decoder
- Use with Tuned Circuit for Narrow Bandwidth, Lower Noise Operation
- Minimum External Components
- Wide Operating Supply Voltage Range
- Low Current Drain
- Improved Retrofit for NEC Part No. μPC1373
- MC14497 Recommended IR Transmitter
- MLED81 Complementary Emitter
- MRD821 Complementary Detector Diode

**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**PIN CONNECTIONS**




**MAXIMUM RATINGS**

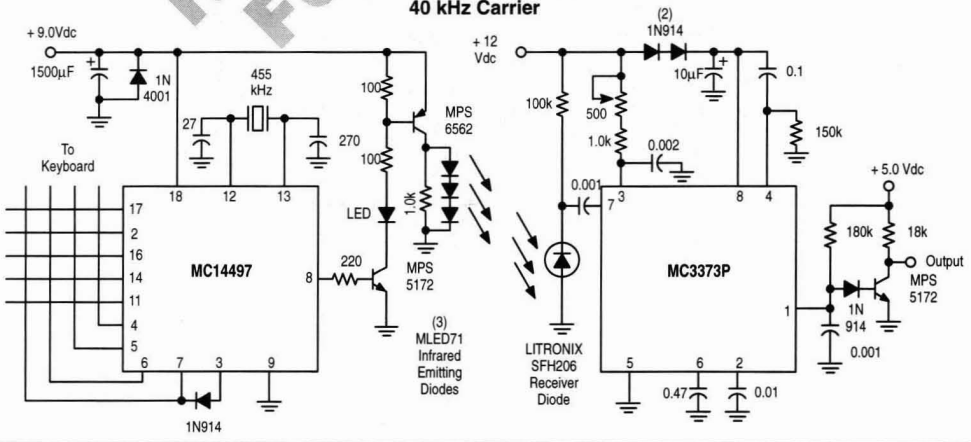
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 15 | Vdc |
| Operating Temperature Range | $T_A$ | 0 to 75 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +125 | °C |
| Junction Temperature | $T_J$ | 150 | °C |
| Power Dissipation, Package Rating<br>Derate above 25°C | $P_D$<br>$1/\theta_{JA}$ | 1.25<br>10 | W<br>mW/°C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3373P | $T_A$ = 0 to +75°C | Plastic DIP |
| MC3373D | | SO–8 |

Not Recommended For New Designs

**Figure 1. Remote Control Application**
**40 kHz Carrier**



**RECOMMENDED OPERATING CONDITIONS**

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage (25°C) | $V_{CC}$ | 4.75 | – | 15 | Vdc |
| Power Supply Voltage (0°C) | $V_{CC}$ | 5.0 | – | 15 | Vdc |
| Input Frequency | $f_{in}$ | 30 | 40 | 80 | kHz |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 5.0 V, $f_{in}$ = 40 kHz, Test circuit of Figure 2)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Current | $I_{CC}$ | 1.5 | 2.5 | 3.5 | mAdc |
| Input Terminal Voltage | V(Pin 7) | 2.4 | 2.8 | 3.0 | Vdc |
| Input Voltage Threshold | $V_{in}$ | – | 50 | 100 | μVpp |
| Input Amplifier Voltage Gain (V[Pin 3] = 500 mVpp) | $A_V$ | – | 60 | – | dB |
| Input Impedance | $r_{in}$ | 40 | 60 | 80 | kΩ |
| Output Voltage, $V_{in}$ = 1.0 mVpp | $V_{OL}$ | – | – | 0.5 | V |
| Output Leakage, $V_{CC}$ = $V_{OH}$ = 15 Vdc | $I_{OH}$ | – | – | 2.0 | μA |
| Output Voltage, Input Open | $V_{OH}$ | – | – | 5.0 | Vdc |

Not Recommended For New Designs

**Figure 2. Test Circuit**

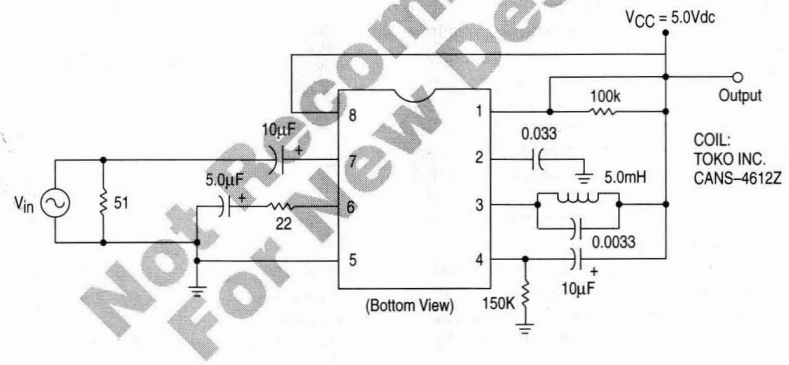



**Figure 3. Representative Block Diagram**

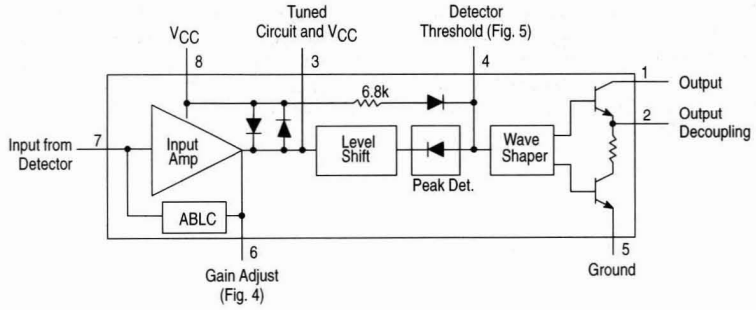



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**Figure 4. Input Amplifier Gain**

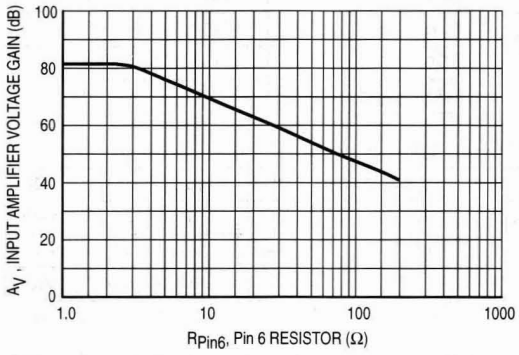
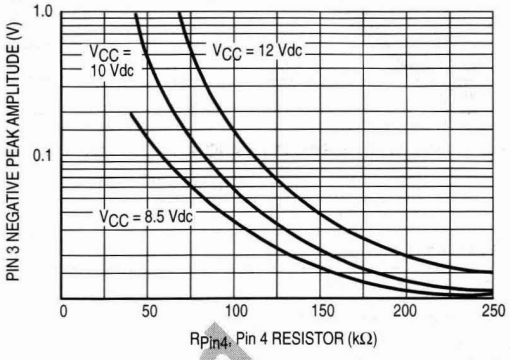



**Figure 5. Detector Threshold**

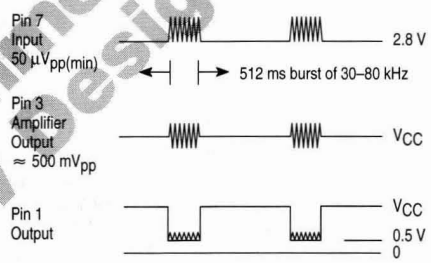



## APPLICATIONS INFORMATION

The MC3373 is a specialized high gain amplifier/signal processor bipolar analog IC designed to be the core of infrared carrier signaling systems. The amplifier section has an Automatic Bias Level Control (ABLC) for simplified direct connection to an IR detector diode. Generally, it is operated ac coupled, utilizing an input high–pass filter to eliminate power line related noise, particularly that from florescent and gas vapor lamps. The use of a high frequency carrier is strongly recommended as opposed to simply detecting "dc" bursts of IR energy. In the carrier mode setup the MC3373 acts like an AM receiver subsystem, amplifying the incoming signal, demodulating it, and providing some basic wave shaping of the demodulated envelope. The tuned circuit at Pin 3 provides the main system selectivity reducing random noise interference and permitting multichannel operation in the same physical area without falsing. In the multichannel case the carriers must not be harmonically related. The bandwidth is determined primarily by the "Q" of the coil. Bandwidth may be increased by loading, shunting, the coil with a resistor.

Since this is a very high gain system operating at relatively high frequencies, care **must** be taken in the circuit layout and construction. Do not use wire wrap or non–ground plane protoboard. A simple single sided PCB with ground fill or a two–sided board with a solid groundplane and top side point–to–point will provide consistent high performance. There is a wide array of IR emitter/detectors available. The Motorola MLED81 and MRD821 are an excellent low cost combination to use with the MC3373. Multiple emitters are recommended for extended range.

**Figure 6. Typical Signal Waveforms**




The input amplifier gain is approximately equal to the load impedance at Pin 3, divided by the resistor from Pin 6 to ground. Again, the low frequency gain can be reduced by using a small coupling capacitor in series with the Pin 6 resistor.

The load may be resistive, with only, or tuned, as in the test circuit. The amplifier output is limited by back–to–back clamping diodes, level shifted, buffered and fed to a negative peak detector. The detector threshold is set by the external resistor on Pin 4, and an internal 6.8 kΩ resistor and diode to $V_{CC}$. The capacitor from $V_{CC}$ to Pin 4 quickly charges during the negative peaks and then settles toward the set–up voltage between signal bursts at a rate roughly determined by the value of the capacitor and the 6.8 k resistor. The external capacitor at Pin 2 filters the ultrasonic carrier from the pulses.

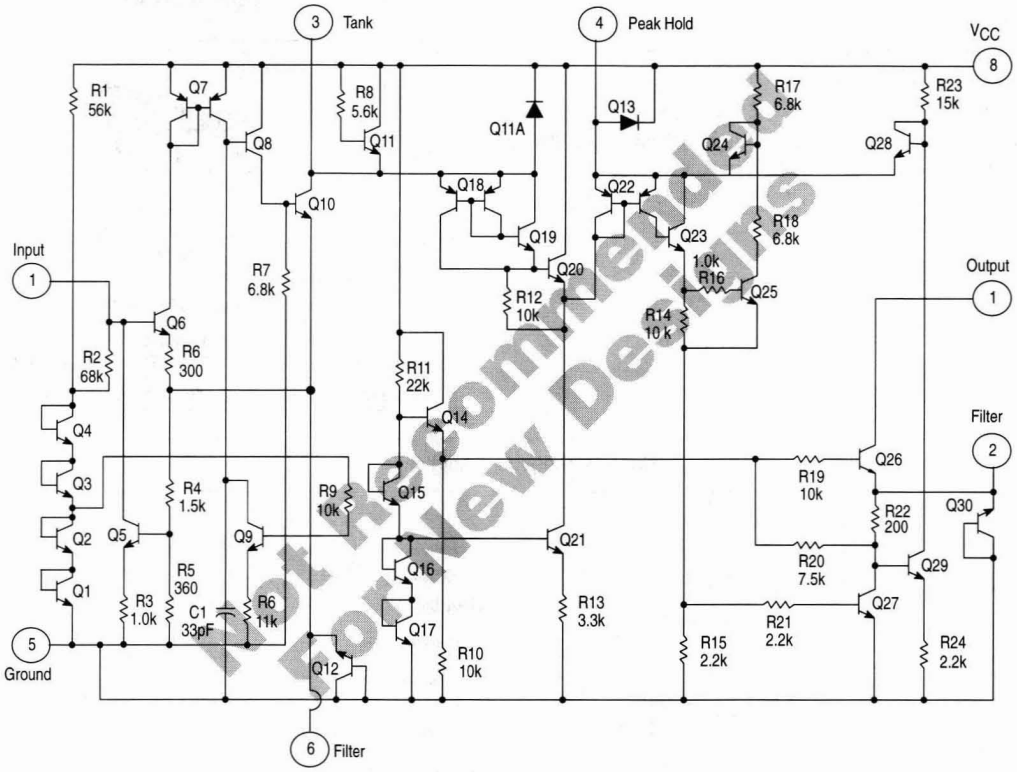
Not Recommended for New Designs

9

## CIRCUIT DESCRIPTION

Q1 to Q4 set the bias on the amplifier input at approximately 2.8 V. Q6 to Q10 form the input amplifier, which has a gain of about 80 dB when R(Pin 6) = 0, Q5 sinks input current from the photo diode and keeps the amplifier properly biased. Q18 to Q20 level shift and buffer the signal to the negative peak detector, Q22 and Q23. Output devices Q26 and Q27 conduct during peaks and pull the output (Pin 1) low. The capacitor on Pin 2 filters out the carrier.

**Figure 7. Representative Schematic Diagram**




Not Recommended For New Designs

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MOTOROLA

# MC13020

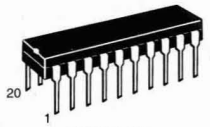
# Motorola C-QUAM® AM Stereo Decoder

This circuit is a complete one ship, full feature AM stereo decoding and pilot detection system. It employs full–wave envelope signal detection at all times for the L + R signal, and decodes L – R signals only in the presence of valid stereo transmission.

- No Adjustments, No Coils
- Few Peripheral Components
- True Full–Wave Envelope Detection for L + R
- PLL Detection for L – R
- 25 Hz Pilot Presence Required to Receive L – R
- Pilot Acquisition Time 300 ms for Strong Signals, Time Extended for Noise Conditions to Prevent "Falsing"
- Internal Level Detector can be used as AGC Source

**MOTOROLA C–QUAM® AM STEREO DECODER**

**SEMICONDUCTOR TECHNICAL DATA**

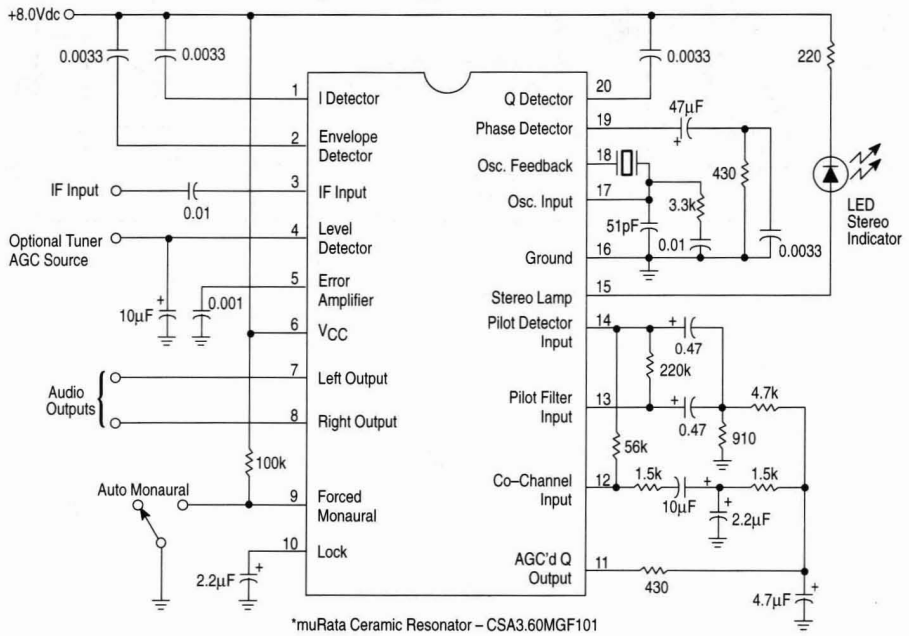



**P SUFFIX**
PLASTIC PACKAGE
CASE 738

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13020P | $T_A$ = – 40 to +85°C | Plastic DIP |

**Figure 1. Simplified Application**




*muRata Ceramic Resonator – CSA3.60MGF101

The purchase of the Motorola C–QUAM® AM Stereo Decoder does not carry with such purchase any license by implication, estoppel or otherwise, under any patent rights of Motorola or others covering any combination of this decoder with other elements including use in a radio receiver. Upon application by an interested party, licenses are available from Motorola on its patents applicable to AM Stereo radio receivers.

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 14 | Vdc |
| Pilot Lamp Current, Pin 15 | | 50 | mAdc |
| Operating Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Power Dissipation<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 8.0 Vdc, $T_A$ = 25°C, Input Signal = 200 mVrms. Unmodulated carrier, circuit of Figure 1, unless otherwise noted.)

| Characteristics | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Line Current Drain, Pin 6 | | 20 | 30 | 40 | mAdc |
| Input Signal Level, Unmodulated, Pin 3, for Full Operation | | 112 | 200 | 357 | mVrms |
| Audio Output Level, 50% Modulation | L only or R only<br>Monaural | 160<br>80 | 220<br>110 | 280<br>140 | mVrms |
| Channel Balance, 50% Modulation, Monaural | | – | – | ±1.0 | dB |
| Output THD, 50% Modulation<br><br>Output THD, 90% Modulation | Monaural<br>Stereo<br>Monaural | –<br>–<br>– | –<br>–<br>– | 0.5<br>1.0<br>1.0 | % |
| Channel Separation, L only or R only, 50% Modulation | | 23 | 30 | – | dB |
| Input Impedance | $R_{in}$<br>$C_{in}$ | 20<br>– | 27<br>6.0 | –<br>– | kΩ<br>pF |
| Output Impedance | | – | 100 | 150 | Ω |
| Pilot Acquisition Time<br>VCO locked (after release of forced monaural)<br>Bad Signal Condition | | <br>–<br>1.48 | <br>280<br>– | <br>300<br>– | <br>ms<br>sec |
| Lock Detector Filter Voltage, Pin 10 | In Lock<br>Out of Lock | 7.7<br>– | 8.0<br>0.8 | –<br>1.0 | Vdc |
| Force to Monaural, Pin 9<br>Pull–Down for Monaural Mode<br><br>Pull–Up for Automatic Mode | | <br>2.0<br>–<br><br>–<br>– | <br>2.5<br>0.15<br><br>3.5<br><0.001 | <br>–<br>1.0<br><br>3.7<br>1.0 | <br>Vdc<br>μA<br><br>Vdc<br>μA |

**Figure 2. Basic Quadrature AM (QUAM)**

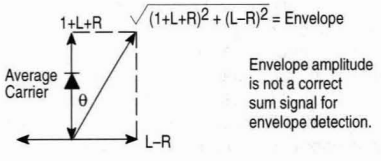



**Figure 3. Motorola C–QUAM®**

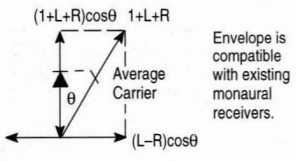



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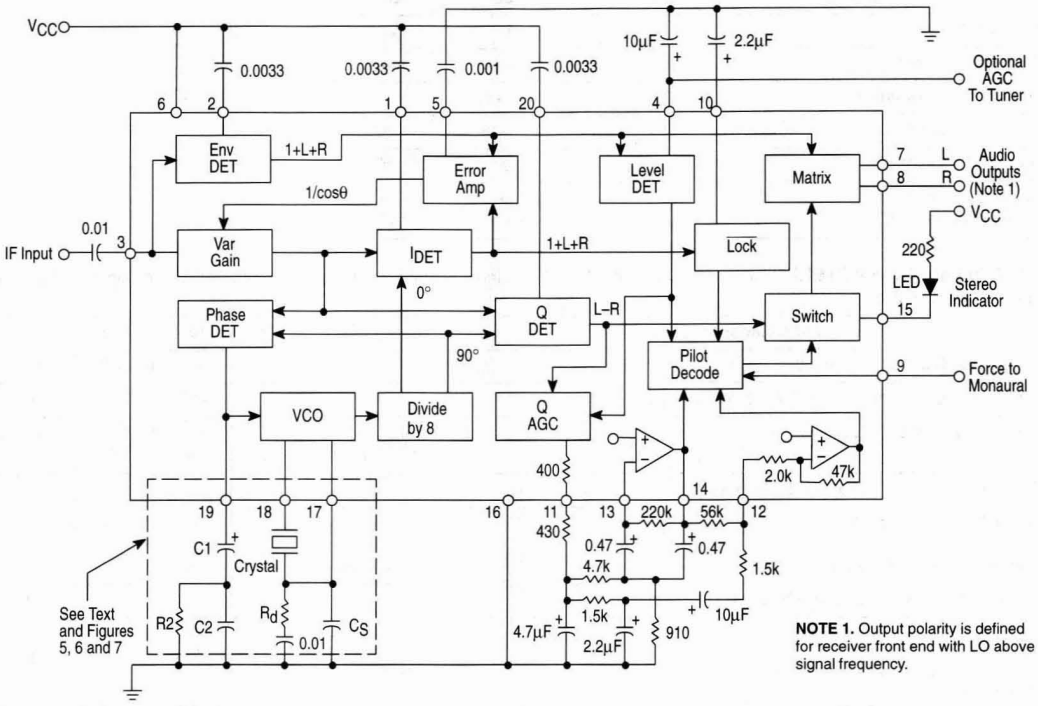
**Figure 4. Representative Block Diagram**




**NOTE 1.** Output polarity is defined for receiver front end with LO above signal frequency.

## MOTOROLA C–QUAM® – COMPATIBLE QUADRATURE AM STEREO

9

### Introduction

In C–QUAM®, conventional quadrature amplitude modulation has been modified by multiplying each axis by cosθ as shown in Figures 2 and 3. The resulting carrier envelope is 1 + L + R, i.e., a correct sum signal for monaural receivers and for stereo receivers operating in monaural mode. A 25 Hz pilot signal is added to the L – R information at a 4% modulation level.

### Decoder

The MC13020P takes the output of the AM IF amplifier and performs the complete C–QUAM® decoding function. In the absence of a good stereo signal, it produces an undegraded monaural output. Note in Figure 4 that the L + R information delivered to the output always comes from the envelope detector (Env DET).

The MC13020P decodes the stereo information by first converting the C–QUAM® signal to QUAM, and then detecting QUAM. The conversion is accomplished by comparing the output of the Env DET and the I DET in the Err AMP. This provides 1/cosθ correction factor, which is then multiplied by the C–QUAM® incoming signal in the Var Gain block. Thus, the output of the Var Gain block is a QUAM signal, which can then be synchronously detected by conventional means. The I and Q detectors are held at 0° and 90° relative demodulation angles by reference signals from the phase–locked, divided–down VCO. The output of the I DET is 1 + L + R, with the added benefit (over the Env DET) of being able to produce a negative output on strong co–channel or noise interference. This is used to tell the Lock circuit to go to monaural operation. The output of the Q DET is the L – R and pilot information.

### VCO

The VCO operates at 8 times the IF input frequency, which ensures that it is out–of–band, even when a 260 kHz IF frequency is used. Typically, a 450 kHz IF frequency is used with synthesized front ends. This places the VCO at 3.6 MHz, which permits economic crystal and ceramic resonators. A crystal VCO is very stable, but cannot be pulled very far to follow front–end mis–tuning. Pull–in capability of ±100 Hz at 450 kHz is typical, and de–Q–ing with a resistor (see Figure 7) can increase the range only slightly. Therefore, the crystal approach can only be used with very accurate, stable front–ends. By comparison, ceramic and L – C VCO circuits offer pull–in range in the order of ±2.5 kHz (at 450 kHz). Ceramic devices accurate enough to avoid trimming adjustment can be obtained with a matched capacitor for Cs (see Figure 1 and 5).

In the PLL filter circuit on Pin 19, C1 is the primary factor in setting a loop corner frequency of 8.0 to 10 Hz, in–lock. An internally controlled fast pull–in is provided. R2 is selected to slightly overdamp the control loop, and C2 prevents high frequency instability.

The Level DET block senses carrier level and provides an optional tuner AGC source. It also operates on the Q AGC block to provide a constant amplitude of 25 Hz pilot at Pin 11, and it delivers information to the pilot decoder regarding signal strength.

**Pilot and Co–Channel Filters**

The Q AGC output drives a low pass filter, made up of 400 Ω internal and 430 Ω and 5 μF external. From this point, an active 25 Hz band–pass filter is coupled to the Pilot Decoder, Pin 14, and another low–pass filter is connected to the Co–channel Input, Pin 12. A 2:1 reduction of 25 Hz pilot level to the Pilot Decode circuit will cause the system to go monaural, with the components shown. Refer to Figure 8 for the formulas governing the active band–pass filter. The co–channel input signal contains any low frequency intercarrier beat notes, and, at the selected level, prevents the Pilot Decode circuit from going into stereo. The co–channel input, Pin 12, gain can be adjusted by changing the external 1.5 k resistor. The values shown set the "trip" level at about 7% modulation. The 25 Hz pilot signal at the output of the active filter is opposite in phase to the pilot signal coming from the second low–pass filter. The 56 k resistor from Pin 14 to Pin 12 causes the pilot to be cancelled at the co–channel input. This allows a more sensitive setting of the co–channel trip level.

**Pilot Decoder**

The Pilot Decoder has two modes of operation. When signal conditions are good, the decoder will switch to stereo after 7 consecutive cycles of the 25 Hz pilot tone. When signal conditions are bad, the detected interference changes the pilot counter so as to require 37 consecutive cycles of pilot to go to stereo. In a frequency synthesized radio. the logic that mutes the audio when tuning can be connected to Pin 9. When this pin is held low it holds the decoder in monaural mode and switches it to the short count. This pin should be held low until the synthesizer and decoder have both locked onto a new station. A 300 ms delay should be sufficient. If the synthesizer logic does not provide sufficient delay, the circuit shown in Figure 9 may be added. Once Pin 9 goes high, the Pilot Decoder starts counting. If no pilot is detected for seven consecutive counts, it is assumed to be a good monaural station and the decoder is switched to the long count. This reduces the possibility of false stereo triggering due to signal level fluctuation or noise. If the PLL goes out of lock, or interference is detected by the co–channel protection circuit before seven cycles are counted, the decoder goes into the long count mode. Each disturbance will reset the counter to zero. The Level Detector will keep the decoder from going into stereo if the IF input level drops 10 dB, but will not change the operation of the pilot counter.

Once the decoder has gone into the stereo mode, it will go instantly back to monaural if either the lock detector on Pin 10 goes low, or if the carrier level drops below the present threshold. Seven consecutive counts of no pilot will also put the decoder in monaural. In stereo, the co–channel input is disabled, and co–channel or other noise is detected by negative excursions of the I DET, as mentioned earlier. When these excursions reach a level caused by approximately 20% modulation of co–channel, the lock detector puts the system in monaural, even though the PLL may still actually be locked. This higher level of co–channel tolerance provides the hysteresis to prevent chattering in and out of stereo on a marginal signal.

When all inputs to the Pilot Decode block are correct, and it has completed its count, it turns on the Switch, sending the L – R to the Matrix, and switches the pilot lamp pin to a low impedance to ground.

**Summary**

It should be noted that in C–QUAM®, with both channels AM modulated, the noise increase in stereo is a maximum of 3.0 dB, less on program material. Therefore, this is not the major concern in the choice of monaural to stereo switching point as it was in FM, and blend is not needed.

**PIN FUNCTION DESCRIPTION**

| Pin | Description |
|---|---|
| 1, 2 | Detector Filters, $R_{out}$ = 4.3 k, recommend 0.0033 μF to $V_{CC}$ to filter 450 kHz components. |
| 3 | IF Signal Input |
| 4 | Level Detector filter pin, $R_{out}$ = 8.2 k, 10 μF to ground sets the AGC time constant. High impedance output, needs buffer. |
| 5 | Error Amp compensation to stabilize the Var Gain feedback loop |
| 6 | $V_{CC}$, 6.0 to 10 Vdc, suitable for low $V_{bat}$ automotive operation, but must be protected from "high line" condition. |
| 7, 8 | Left and Right Outputs, NPN emitter–followers |
| 9 | Forced Monaural, MOS or TTL controllable |
| 10 | Lock detector filter, $R_{out}$ = 27 k, recommend 2.2 μF to ground |
| 11 | AGC'd Q output, NPN emitter–follower with 400 Ω from emitter to Pin 11 |
| 12 | Co–channel input, 2.0 k series in and 47 k feedback |
| 13 | Pilot Filter input to op amp, see Figure 8. |
| 14 | Pilot Decode Input (op amp output) emitter–follower, $R_{out}$ = 100 Ω |
| 15 | Stereo Lamp, open–collector of an NPN common emitter stage, can sink 50 mA, $V_{sat}$ = 0.3 V at 5.0 mA. |
| 16 | Ground |
| 17 | Oscillator input, $R_{in}$ = 10k, do not DC connect to Pin 18 or ground. |
| 18 | Oscillator feedback, NPN emitter, $R_{out}$ = 100 Ω |
| 19 | Phase Detector output, current source to filter. |
| 20 | Detector Filter, $R_{out}$ = 4.3 k, recommend 0.0033 μF to $V_{CC}$ to filter 450 kHz. |

9

**Figure 5. Ceramic VCO**

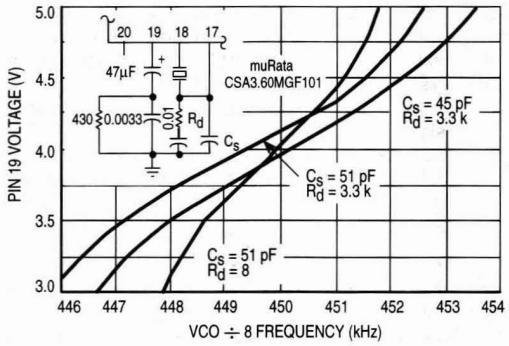



**Figure 6. L–C VCO**

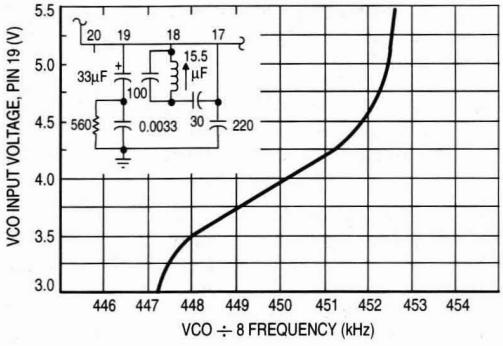



**Figure 7. Crystal VCO**

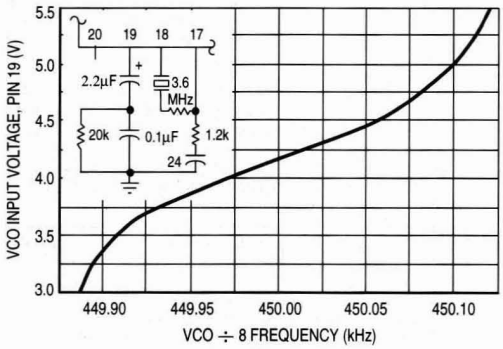



**Figure 8. Forced Monaural Optional Delay Circuit**

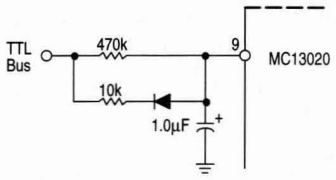
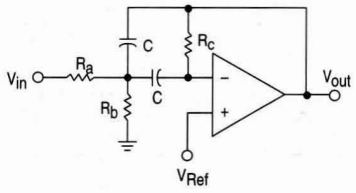



**Figure 9. Active Bandpass Filter**




$$R_c = \frac{Q}{\pi f_O C}$$

$$R_a = \frac{R_c}{2 A_o}$$

$$R_b = \frac{R_a R_c}{4Q^2 R_a - R_c}$$

| C ± 5% | $R_a$ ± 5% | $R_b$ ± 1% | $R_c$ ± 1% |
|---|---|---|---|
| 0.47 µF | 4.7 k | 910 | 220 k |
| 0.33 µF | 8.2 k | 1.3 k | 330 k |

**NOTE:** Capacitor C should be a good grade, low ESR.

Where in this application: $f_O$ = center frequency = 25 Hz
$A_o$ = gain at $f_O \leq 25$
$Q \leq 10$

Choose values for $f_O$, $A_o$, Q, and convenient C, solve for resistors.

MOTOROLA

# MC13022

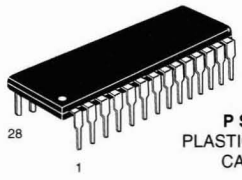
# Advanced Medium Voltage AM Stereo Decoder

The MC13022 is designed for home, portable and automotive AM stereo radio applications. The circuits and functions included in the design allow implementation of a full–featured C–QUAM® AM stereo radio with relatively few, inexpensive external parts. It is available in either 28–lead DIP or EIAJ compatible wide–bodied 28–lead SOIC.

- Operation from 4.0 V to 10 V Supply with Current Drain of 18 mA Typ
- IF Amplifier with Two Speed AGC
- Post Detection Filters that Allow Manual or Automatic Adjustable Audio Bandwidth Control and 9.0 or 10 kHz Notch Filtering
- Signal Quality Controlled Stereo Blend and Noise Reduction
- Noise and Co–Channel Discriminating Stop–On–Station
- Signal Strength Indicator Output for RF AGC and/or Meter Drive
- Signal Strength Controlled IF and Audio Bandwidth
- Noise Immune Pilot Detector Needs no Precision Filter Components
- MC13023 Complementary Tuning System IC

**C–QUAM ADVANCED MEDIUM VOLTAGE AM STEREO DECODER**

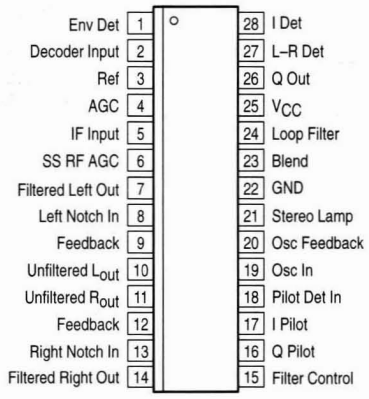
**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 710

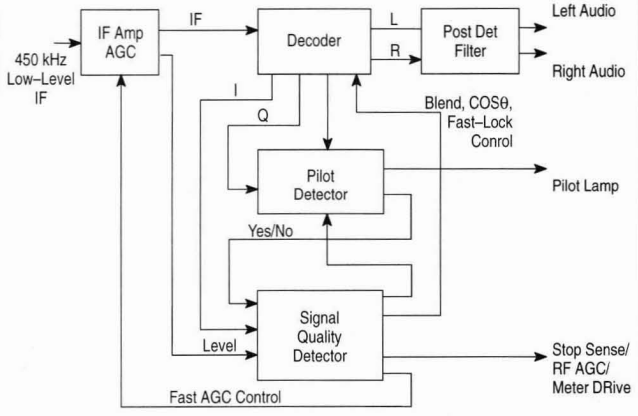
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F
(SO–28L)

**PIN CONNECTIONS**




(Top View)

**Simplified Application**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13022P | $T_A$ = – 40° to +85°C | Plastic Power |
| MC13022DW | | SO–28L |

9

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 12 | Vdc |
| Stereo Indicator Lamp Current (Pin 21) | – | 30 | mAdc |
| Operating Ambient Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Operating Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Power Dissipation<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 8.0 V, $T_A$ = 25°C, Test Circuit of Figure 1, unless otherwise noted.)

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Power Supply Operating Range | 4.0 | 8.0 | 10 | Vdc |
| Supply Line Current Drain (Pin 25) | 11 | 16 | 22 | mAdc |
| Minimum Input Signal Level, Unmodulated for Full Operation (Pin 5) | – | 5.0 | – | mVrms |
| Audio Output Level, 50% Modulation, L only or R only (Pins 10, 11)<br>Stereo | 100 | 140 | 180 | mVrms |
| Audio Output Level, 50% Modulation (Pins 10, 11)<br>Monaural | 50 | 70 | 90 | mVrms |
| Output THD, 50% Modulation<br>Monaural<br>Stereo | <br>–<br>– | <br>0.3<br>0.5 | <br>0.5<br>2.0 | % |
| Channel Separation, L only or R only, 50% Modulation<br>Stereo | 22 | 35 | – | dB |
| Pilot Acquisition Time Following Blend Reset to 0.3 Vdc | – | – | 600 | ms |
| Audio Output Impedance at 1.0 kHz (Pins 7, 14) | – | 300 | – | Ω |
| Stereo Indicator Lamp Pin<br>Saturation Voltage at 3.0 mA Load Current ($V_{sat}$ Pin 21) | – | – | 200 | mVdc |
| Stereo Indicator Lamp Pin<br>Leakage Current (Pin 21) | – | – | 1.0 | μAdc |
| Notch Filter Control (Pin 15), Response versus Voltage | (See Figure 2) | | | |

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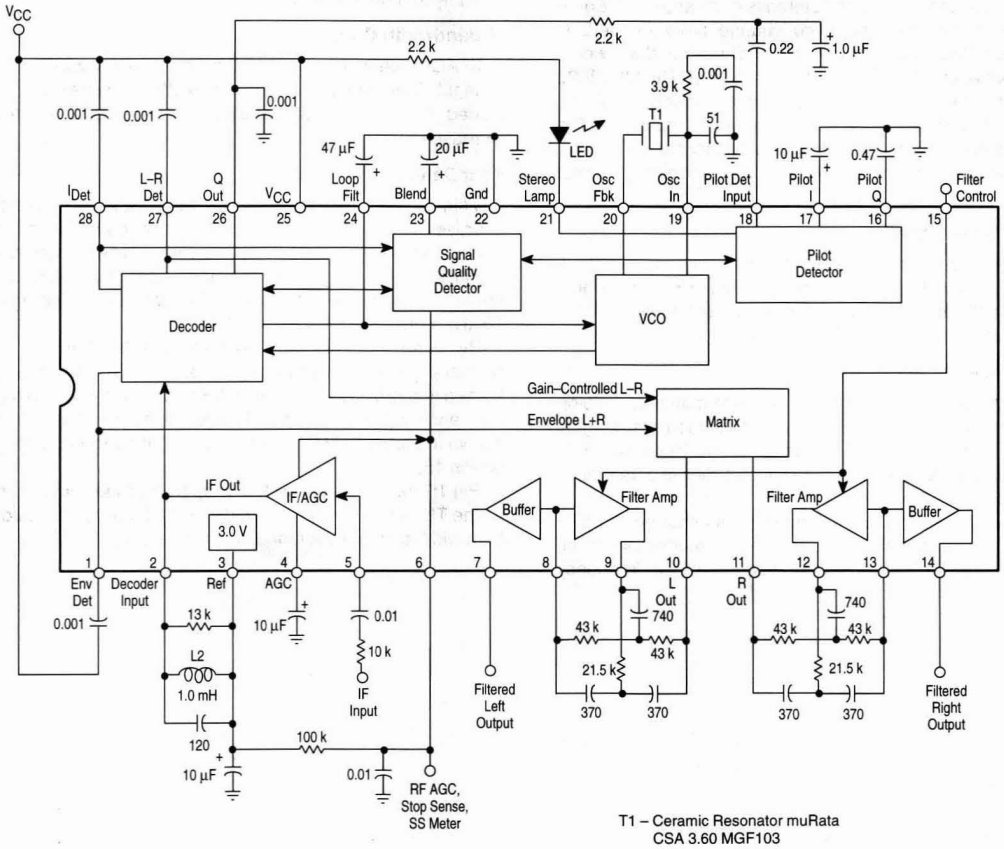
**Figure 1. Test Circuit**




T1 – Ceramic Resonator muRata
CSA 3.60 MGF103
L2 – Miller 9230–92

9

## EXPLANATION OF FEATURES

### Blend and Noise Reduction

Although AM stereo does not have the extreme difference in S/N between mono and stereo that FM does (typically less than 3.0 dB versus greater than 20 dB for FM), sudden switching between mono and stereo is quite apparent. Some forms of interference such as co–channel have a large L–R component that makes them more annoying than would ordinarily be expected for the measured level. The MC13022 measures the interference level and reduces L–R as interference increases, blending smoothly to monaural. The pilot indicator remains on as long as a pilot signal is detected, even when interference is severe, to minimize annoying pilot light flickering.

### RF AGC/Meter Drive

A dc voltage proportional to the log of signal strength is provided at Pin 6. This can be used for RF AGC, signal strength indication, and/or control of the post detection filter. Normal operation is above 2.2 V as shown is Figure 4.

### Stop Sense

Multiplexed with the signal strength information is the stop sense signal. The stop sense is activated when scanning by externally pulling the blend capacitor on Pin 23 below 0.5 V. This would typically be done from the mute line in a frequency synthesizer.

If at any time Pin 23 is low and there is either no signal in the IF or a noisy signal of a predetermined interference level, Pin 6 will go low. This low can be used to tell the frequency synthesizer to immediately scan to the next channel. The interference detection prevents stopping on many unlistenable stations, a feature particularly useful at night when many frequencies may have strong signals from multiple co–channel stations.

### IF Bandwidth Control

IF AGC attenuates the signal by shunting the signal at the IF input. This widens the IF bandwidth by decreasing the loaded Q of the input coupling coil as signal strength increases.

### Post Detection Filtering

With weak, noisy signals, high frequency rolloff greatly improves the sound. Conventional tone controls do not attenuate the highs sufficiently to control noise without also significantly affecting the mid–range. Also, notch filters are necessary with any wide–band AM radio to eliminate the 10 kHz whistle from adjacent stations.

By using a twin–T filter with variable feedback to the normally grounded center leg, a variable Q notch filter is formed that provides both the 10 kHz notch and variable high frequency rolloff functions. Typical range of response is shown in Figure 3. Response is controlled by the dc voltage on Pin 15.

Pin 15 could interface with a dc operated tone control such as the TDA1524, or could be tied to Pin 6 for automatic audio bandwidth control as a function of signal strength.

**Figure 2. High Performance Home Type AM Stereo Receiver**

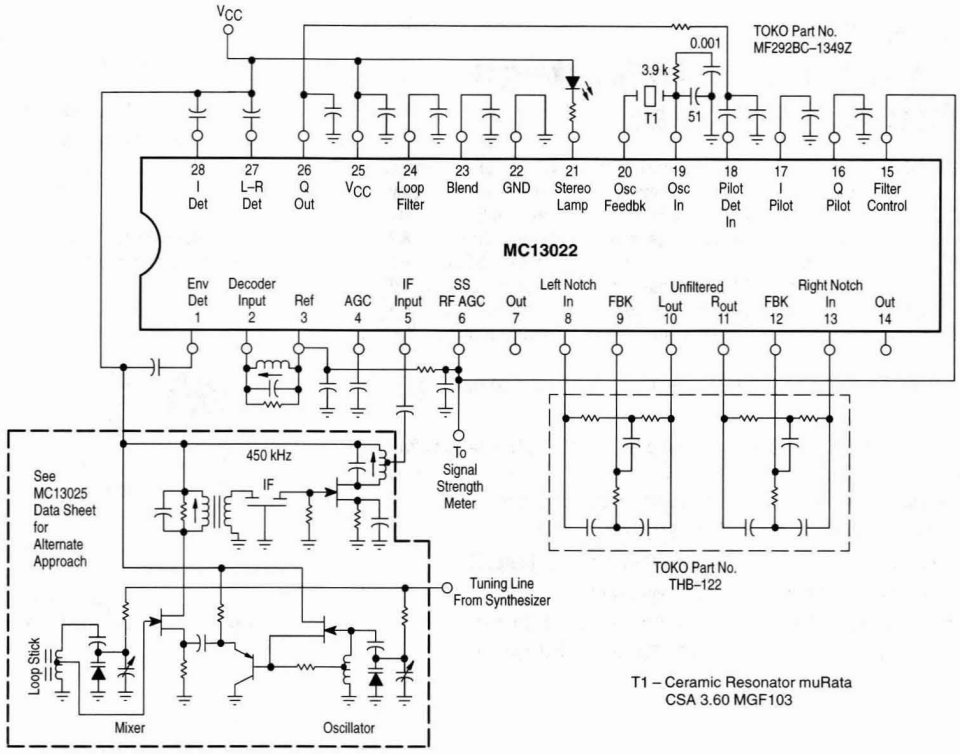



**Figure 3. Overall Selectivity of a Typical Receiver versus Filter Control Voltage**

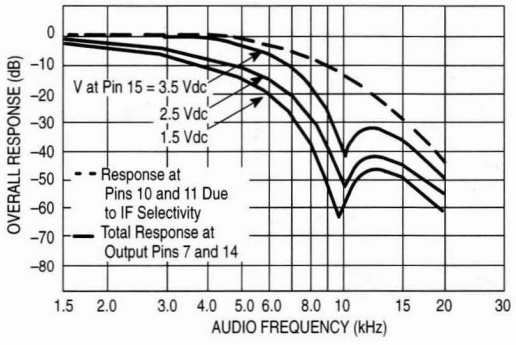
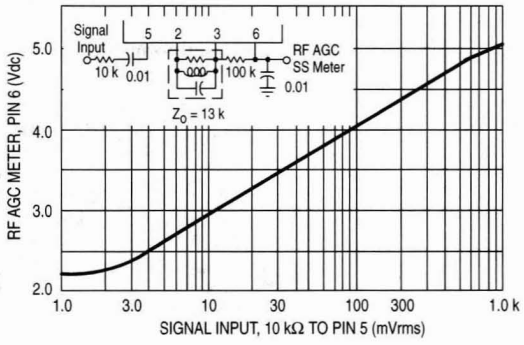



**Figure 4. RF AGC/Signal Strength Output versus Input Signal**




9

MOTOROLA

# MC13022A

*Advance Information*

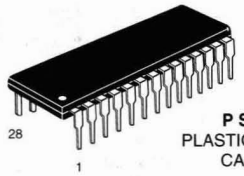
## Advanced Medium Voltage AM Stereo Decoder

**C–QUAM ADVANCED MEDIUM VOLTAGE AM STEREO DECODER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13022A is designed for home and automotive AM stereo radio applications. The circuits and functions included in the design allow implementation of a full–featured C–QUAM® AM stereo radio with relatively few, inexpensive external parts. It is available in either 28–lead DIP or EIAJ compatible wide–bodied 28–lead SOIC. Functionally, the MC13022A and MC13022 are very similar. The MC13022A has 10 dB more audio output and a CMOS compatible logic level output (Pin 15) for stop sense. The stop sense/AGC function has been internally connected to the output notch filter control.

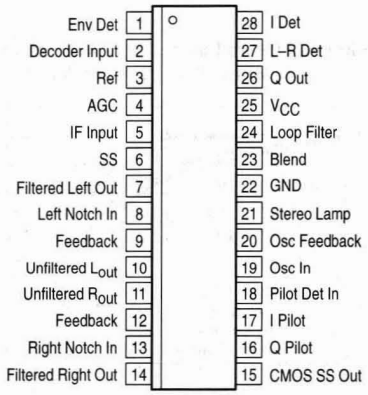
- Operation from 6.0 V to 10 V Supply with Current Drain of 20 mA Typ
- IF Amplifier with Two Speed AGC
- Post Detection Filters that Allow Automatic Adjustable Audio Bandwidth Control and Notch Filtering (9.0 or 10 kHz)
- Signal Quality Controlled Stereo Blend and Noise Reduction
- Noise and Co–Channel Discriminating Stop–On–Station
- Signal Strength Indicator Output for Stop Sense and/or Meter Drive
- Signal Strength Controlled IF and Audio Bandwidth
- Noise Immune Pilot Detector Needs no Precision Filter Components
- MC13025 Complementary Electronically Tuned Radio Front End
- CMOS Compatible Driver for Stop Sense




**P SUFFIX**
PLASTIC PACKAGE
CASE 710

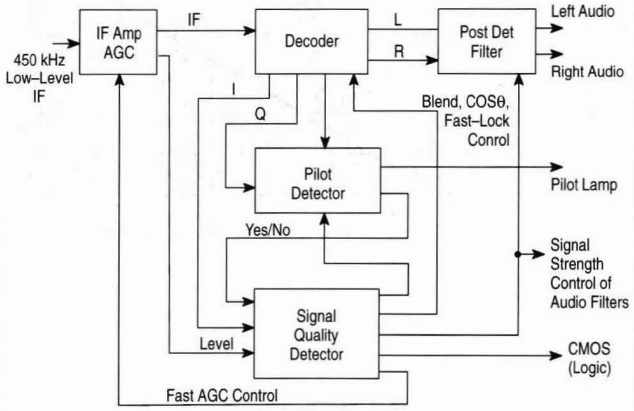
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F
(SO–28L)

**PIN CONNECTIONS**




(Top View)

**Simplified Application**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13022AP | $T_A$ = – 40° to +85°C | Plastic Power |
| MC13022ADW | | SO–28L |

9

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 12 | Vdc |
| Stereo Indicator Lamp Current (Pin 21) | – | 30 | mAdc |
| Operating Ambient Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Operating Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Power Dissipation<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

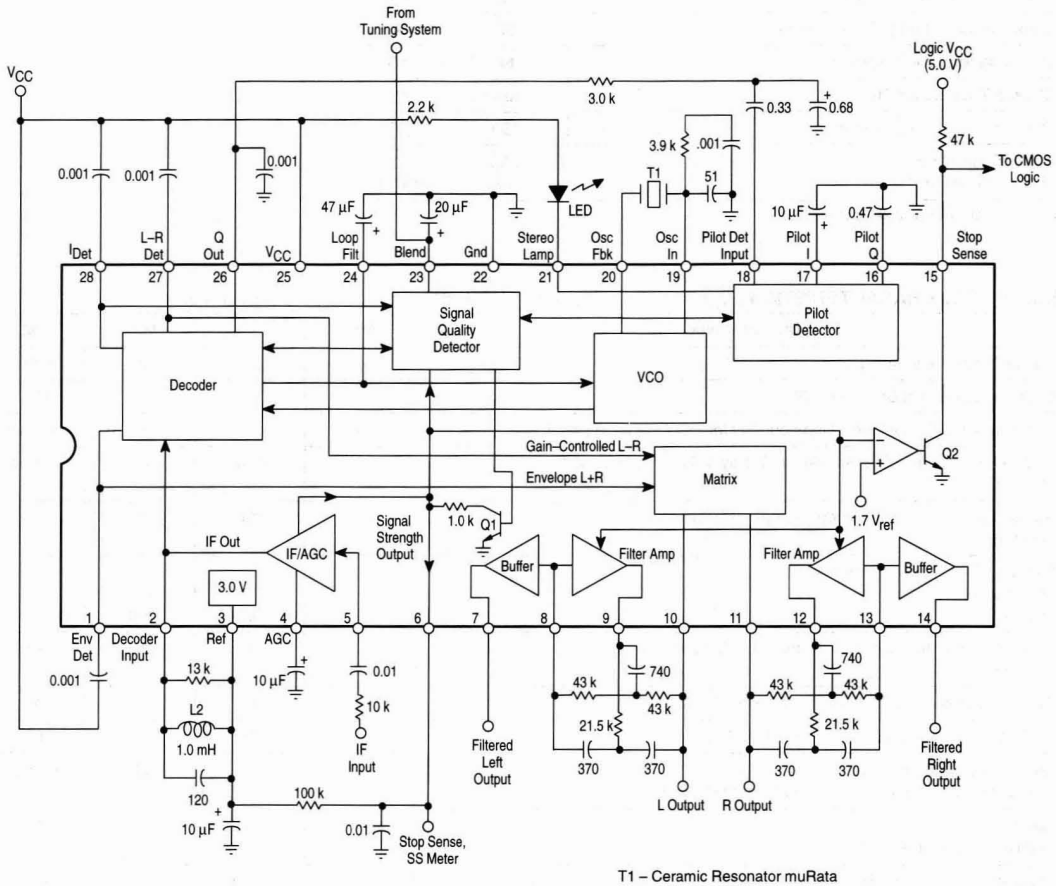
**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 8.0 V, $T_A$ = 25°C, Test Circuit of Figure 1, unless otherwise noted.)

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Power Supply Operating Range | 6.0 | 8.0 | 10 | Vdc |
| Supply Line Current Drain (Pin 25) | 10 | 20 | 25 | mAdc |
| Minimum Input Signal Level, Unmodulated for Full Operation (Pin 5) | – | 5.0 | – | mVrms |
| Audio Output Level, 50% Modulation, L only or R only (Pins 10, 11)<br>Stereo | 290 | 400 | 530 | mVrms |
| Audio Output Level, 50% Modulation (Pins 10, 11)<br>Monaural | 140 | 200 | 265 | mVrms |
| Output THD, 50% Modulation<br>Monaural<br>Stereo | <br>–<br>– | <br>0.3<br>0.5 | <br>0.8<br>1.6 | %<br><br> |
| Channel Separation, L only or R only, 50% Modulation<br>Stereo | 22 | 35 | – | dB |
| Pilot Acquisition Time Following Blend Reset to 0.3 Vdc | – | – | 600 | ms |
| Audio Output Impedance at 1.0 kHz (Pins 7, 14) | – | 300 | – | Ω |
| Stereo Indicator Lamp Pin<br>Saturation Voltage at 3.0 mA Load Current ($V_{sat}$ Pin 21) | – | – | 200 | mVdc |
| Stereo Indicator Lamp Pin<br>Leakage Current (Pin 21) | – | – | 1.0 | µAdc |
| Oscillator Capture Range | – | ±3.0 | – | kHz |

9

**Figure 1. Test Circuit**




T1 – Ceramic Resonator muRata
CSA 3.60 MGF103
L2 – Miller 9230–92

**NOTES:** 1. Q1 is switched on when the Blend Pin 23 is externally held low and the signal is weak or has 110% negative modulation. In this condition Q1 pulls Pin 6 low (0.25 to 1.3 V). At all other times, Pin 6 follows the curve in Figure 4.
2. Q2 (Pin 15) is switched on when Pin 6 voltage is below 1.7 V. Q2 could then be used as a logic output to the tuning system, telling the tuning system to continue searching for a good signal.
3. User is cautioned not to require more than 1.0 mA from Pin 6.

## EXPLANATION OF FEATURES

### Blend and Noise Reduction

Although AM stereo does not have the extreme difference in S/N between mono and stereo that FM does (typically less than 3.0 dB versus greater than 20 dB for FM), sudden switching between mono and stereo is quite apparent. Some forms of interference such as co–channel have a large L–R component that makes them more annoying than would ordinarily be expected for the measured level. The MC13022A measures the interference level and reduces L–R as interference increases, blending smoothly to monaural. The pilot indicator remains on as long as a pilot signal is detected, even when interference is severe, to minimize annoying pilot light flickering.

### Signal Strength

A dc voltage proportional to the log of signal strength is provided at Pin 6. This can be used for signal strength indication, and it directly controls the post detection filter. Normal operation is above 2.2 V as shown is Figure 4.

### Stop Sense

The signal strength information is multiplexed with the stop sense signal. The stop sense is activated when scanning by externally pulling the blend, Pin 23, below 0.3 V. This would typically be done from the mute line in a frequency synthesizer.

If at any time Pin 23 is low and there is either no signal in the IF or a noisy signal of a predetermined interference level, Pins 6 and 15 will go low. This low can be used to tell the frequency synthesizer to immediately scan to the next channel. The interference detection prevents stopping on many unlistenable stations, a feature particularly useful at night when many frequencies may have strong signals from multiple co–channel stations. Pin 6 drives a comparator which has a 1.7 V reference. Therefore the comparator output, Pin 15, is low if Pin 6 is <1.7 V and high if Pin 6 is >1.7 V.

### IF Bandwidth Control

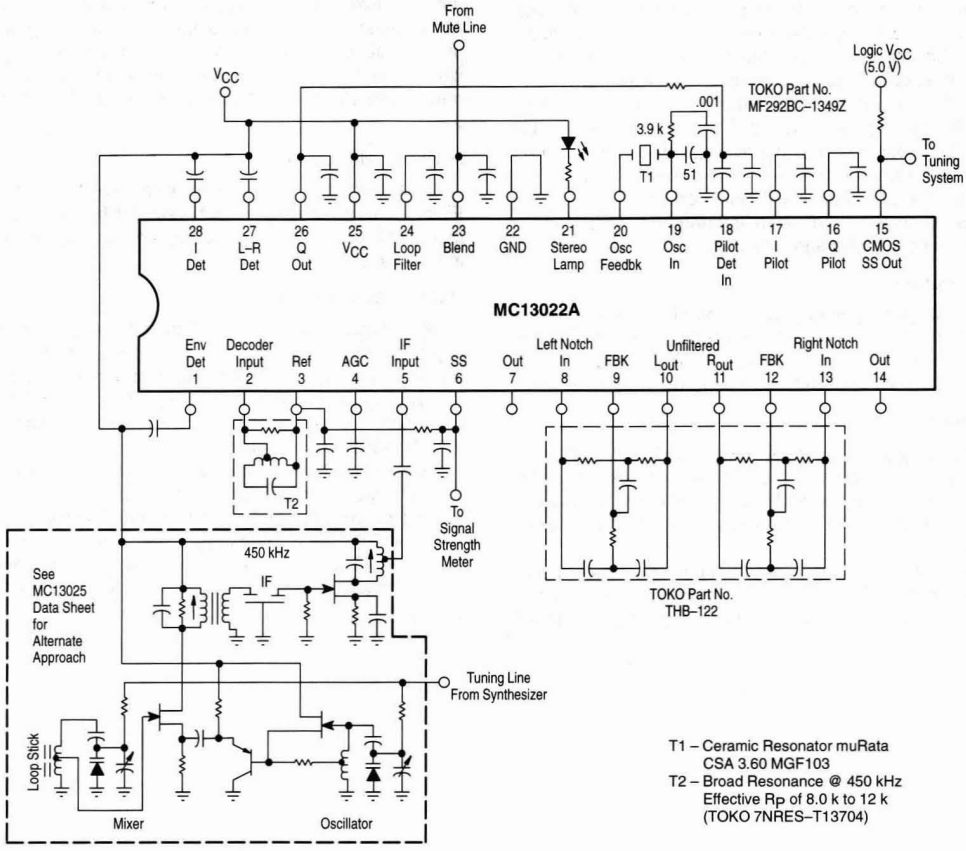
IF AGC attenuates the signal by shunting the signal at the IF input. This widens the IF bandwidth by decreasing the loaded Q of the input coupling coil as signal strength increases.

### Post Detection Filtering

With weak, noisy signals, high frequency rolloff greatly improves the sound. Conventional tone controls do not attenuate the highs sufficiently to control noise without also significantly affecting the mid–range. Also, notch filters are necessary with any wide–band AM radio to eliminate the 10 kHz whistle from adjacent stations.

By using a twin–T filter with variable feedback to the normally grounded center leg, a variable Q notch filter is formed that provides both the 10 kHz notch and variable high frequency rolloff functions. Typical range of response is shown in Figure 3. Response is controlled by Pin 6 for automatic audio bandwidth control as a function of signal strength.

**Figure 2. High Performance Home Type AM Stereo Receiver**




T1 – Ceramic Resonator muRata CSA 3.60 MGF103
T2 – Broad Resonance @ 450 kHz Effective $R_P$ of 8.0 k to 12 k (TOKO 7NRES–T13704)

**Figure 3. Overall Selectivity of a Typical Receiver versus Filter Control Voltage**

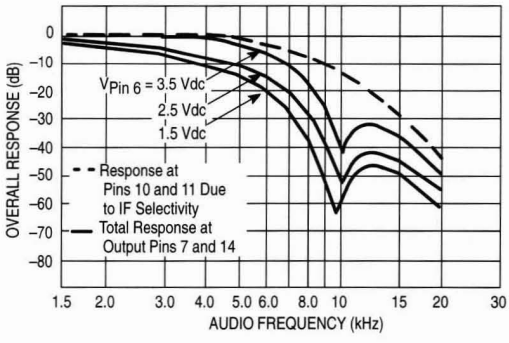
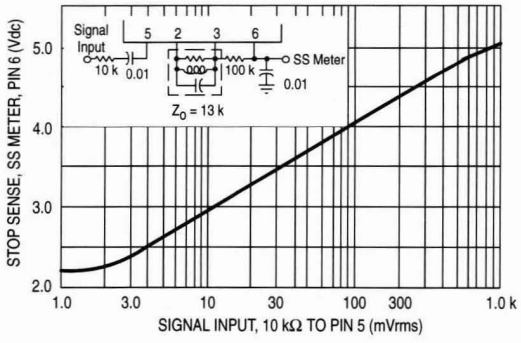



**Figure 4. Strength Output versus Input Signal**



MOTOROLA

# MC13025

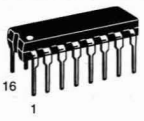
# Electronically Tuned Radio Front End

**ETR® FRONT END for C–QUAM® AM STEREO**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13025 is the complementary ETR® Electronically Tuned Radio front–end for the second generation MC13022 C–QUAM® AM stereo IF and decoder. The MC13025 provides a high dynamic range mixer, voltage controlled oscillator, and first IF that with the MC13022 and synthesizer form a complete digitally controlled AM stereo tuner system. This system in turn may drive a dual channel audio processor and high power amplifiers for car radio or home stereo applications. Other applications include portable radio "boom boxes", table radios and component stereo systems.

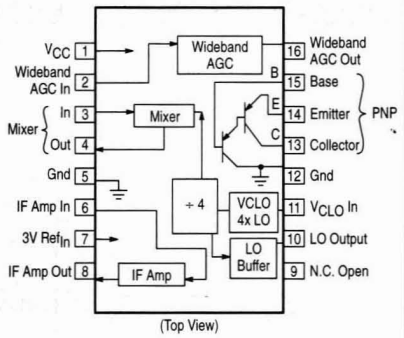
- Operates Over a Wide Range of Supply Voltages: 6.0 $V_{CC}$ to 10 $V_{CC}$
- Wideband AGC Voltage to RF Amp for Extended Dynamic Range
- Buffered VCO Output to Frequency Synthesizer
- No External RF Amp Needed for Most Home Stereo and Portable Radios
- IF Drive Output Matches the MC13022 for Optimum Performance
- VCO Operates at Four Times Local Oscillator Injection Frequency




**P SUFFIX**
PLASTIC PACKAGE
CASE 648

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

**PIN CONNECTIONS**

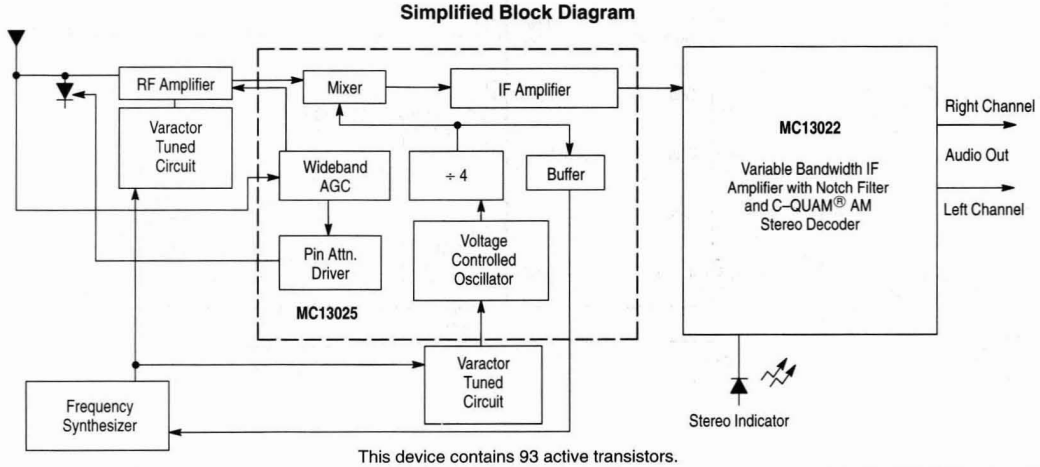



(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13025D | $T_A = -40°$ to $+85°C$ | SO–16 |
| MC13025P | | Plastic DIP |

**Simplified Block Diagram**




This device contains 93 active transistors.

9

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 12 | Vdc |
| Ambient Operating Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Junction Temperature | $T_J$ | 150 | °C |
| Power Dissipation<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, 8.0 $V_{CC}$ test circuit as shown in Figure 2.)

| Characteristics | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current | 1 | 7.0 | 8.2 | 10 | mAdc |
| 3.0 V Ref, Current In | 7 | –50 | 7.0 | 90 | µAdc |
| IF Out DC Current | 8 | 0.9 | 1.05 | 1.2 | mAdc |
| Mixer DC Current Output | 4 | 0.70 | 0.77 | 0.82 | mAdc |
| IF Output Amplitude, RF Input @ 1.7 MHz, 31.6 mV | 8 | 270 | 330 | 390 | mVrms |
| Local Oscillator Output | 10 | 160 | 181 | 220 | mVrms |
| Wideband AGC Pull–Down Current | 16 | 0.5 | 1.0 | 1.5 | mAdc |
| PNP Darlington (DC Beta @ 5.0 mA $I_E$) | | 1000 | 2500 | – | |
| PNP Darlington Collector Leakage ($V_E$ = $V_B$ = 8.0 V) | 13 | –0.13 | –0.06 | – | µAdc |

**Figure 1. Test Circuit**

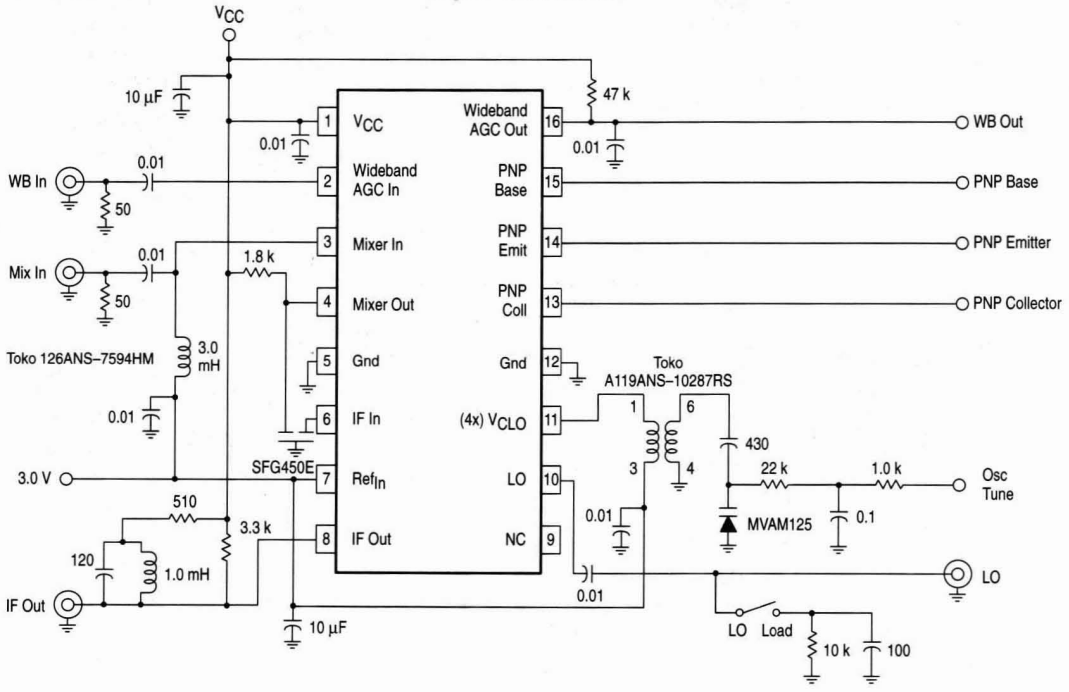
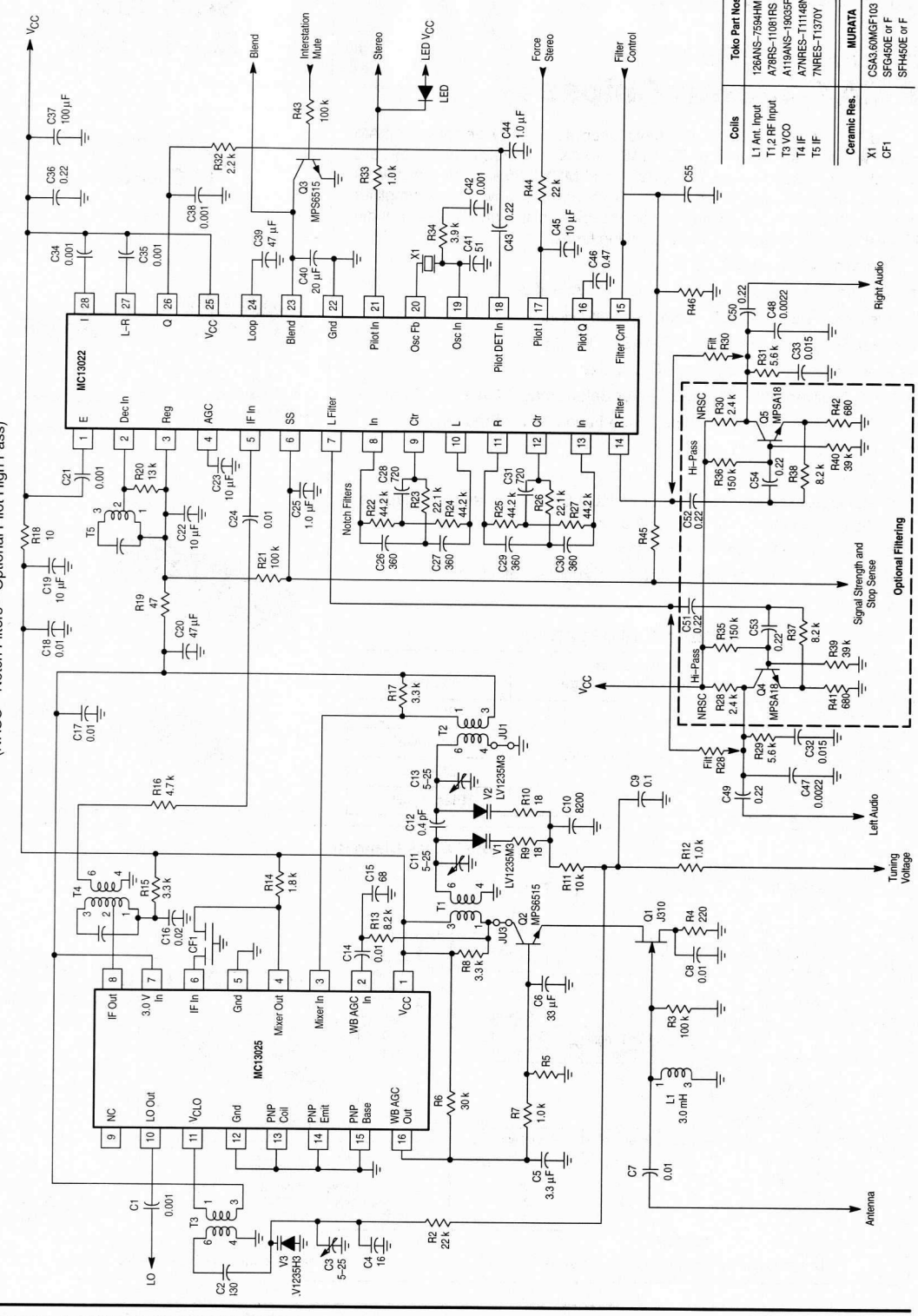


**Figure 2. Cascade RF ETR Application**
(NRSC – Notch Filters – Optional Pilot High Pass)



MOTOROLA

# MC13027
# MC13122

*Product Preview*

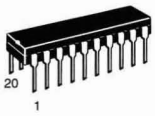
## AMAX Stereo Chipset

**AMAX STEREO IC CHIPSET**

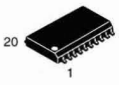
The MC13027 and MC13122 have been specifically designed for AM radio which can meet the EIA/NAB AMAX requirements. They are essentially the same as the MC13022A and MC13025 with the addition of noise blanking circuitry. The noise blanker consists of a wide band amplifier with an RF switch for blanking ahead the IF amplifier and a stereo audio blanker with adjustable delay and blanking times.

- Operating Voltage Range of 6.0 V to 10 V
- RF Blanker with Built–In Wide Band AGC Amplifier
- Audio Noise Blanker with Audio Track and Hold
- Mixer Third Order Intercept of 8.0 dBm (115 dBμV)
- Wide Band AGC Detector for RF Amplifier
- Local Oscillator VCO Divide–by–4 for Better Phase Noise
- Buffered Local Oscillator Output at the Fundamental Frequency
- Fast Stereo Decoder Lock
- Soft Stereo Blend
- Signal Quality Detector to Control Variable Q–Notch Filters for Adaptive Audio Bandwidth and Whistle Reduction
- Signal Quality Detector for AM Stereo
- Very Low Distortion Envelope and Synchronous Detectors
- Variable Bandwidth IF

**MC13027**

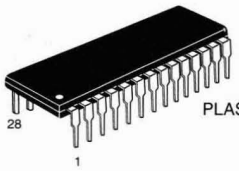



**P SUFFIX**
PLASTIC PACKAGE
CASE 738




**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**MC13122**



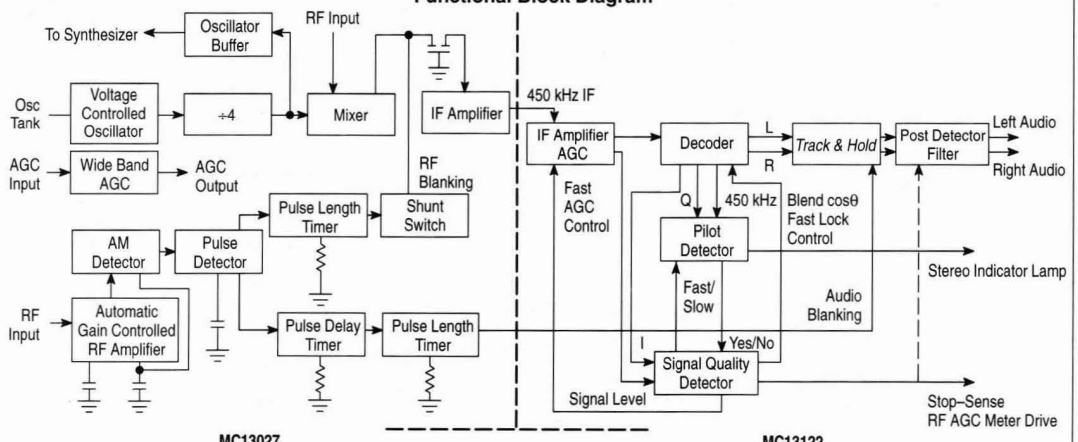

**P SUFFIX**
PLASTIC PACKAGE
CASE 710

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F
(SO–28L)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13027DW | $T_A$ = –40 ° to +85°C | SO–20L |
| MC13027P | | Plastic DIP |
| MC13122DW | | SO–28L |
| MC13122P | | Plastic DIP |

**Functional Block Diagram**




This device contains 428 active transistors.

This device contains 670 active transistors.

9

**MC13027**
**MAXIMUM RATINGS**

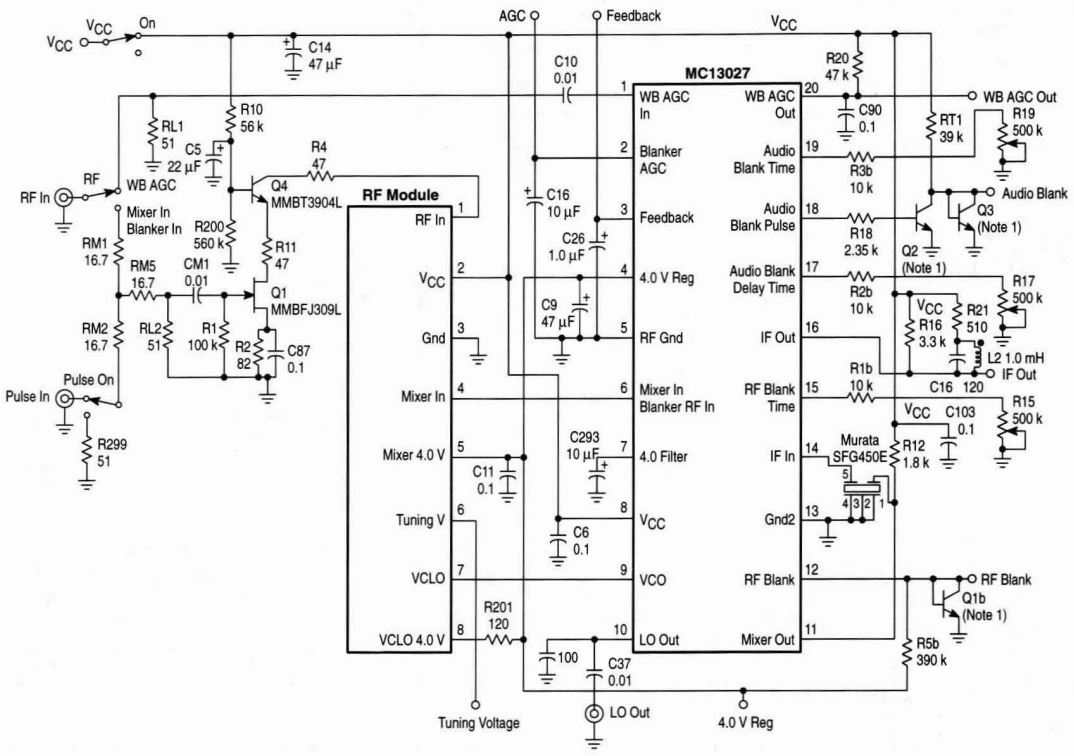
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 12 | Vdc |
| Ambient Operating Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –60 to +150 | °C |
| Operating Junction Temperature | $T_J$ | 150 | °C |

**NOTE:** ESD data available upon request.

**MC13027**
**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, 8.0 $V_{CC}$ Test Circuit as shown in Figure 1.)

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Supply Voltage Range (Pin 8) | – | 6.0 to 10 | – | V |
| Wideband (WB) AGC Threshold | – | 1.0 | – | mVrms |
| IF Output DC Current | – | 1.0 | – | mAdc |
| Mixer DC Current Output | – | 0.83 | – | mAdc |
| Local Oscillator Output | – | 600 | – | mVpp |
| Wideband AGC Pull–Down Current (Pin 20) | – | 1.0 | – | mAdc |
| Power Supply Current | – | 16 | – | mAdc |
| Mixer 3rd Order Intercept Point (Pin 6) | – | 8.0 | – | dBm |
| Mixer Conversion Gain | – | 2.9 | – | mS |
| IF Amplifier Input Impedance (Pin 14) | – | 2.2 | – | kΩ |
| IF Amplifier Transconductance | – | 2.8 | – | mS |
| IF Amplifier Load Resistance (Pin 16) | – | 5.7 | – | kΩ |
| IF Amplifier Collector Current (Pin 16) | – | 990 | – | μA |

**Figure 1. MC13027 Test Circuit**




**NOTE:** 1. General purpose NPN transistor 2N3904 or equivalent.

**MC13122**
**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 12 | Vdc |
| Stereo (Pilot) Indicator Lamp Current (Pin 21) | – | 30 | mAdc |
| Operating Ambient Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Operating Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Power Dissipation Derated above 25°C | $P_D$ | 1.25<br>10 | Ω<br>mW/C |

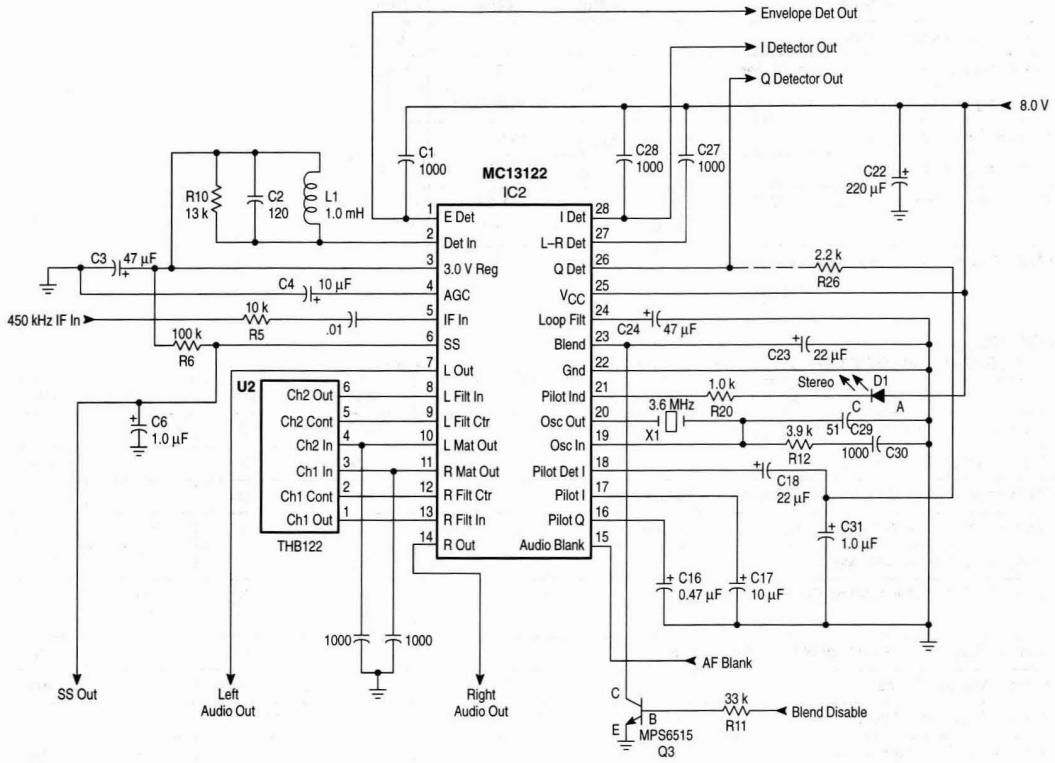
**NOTE:** ESD data available upon request.

**MC13122**
**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 8.0 V, $T_A$ = 25°C, Test Circuit of Figure 2.)

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Power Supply Operating Range | 6.0 | 8.0 | 10 | V |
| Supply Current Drain (Pin 25) | 10 | 20 | 25 | mA |
| Minimum Input Signal Level, Unmodulated, for AGC Start | – | 5.0 | – | mV |
| Audio Output Level, 50% Modulation, L Only or R Only | 290 | 400 | 530 | mVrms |
| Audio Output Level, 50% Mono | 140 | 200 | 265 | mVrms |
| Output THD, 50% Modulation (Monaural Stereo) | –<br>– | 0.3<br>0.5 | 0.8<br>1.6 | % |
| Channel Separation, L Only or R Only, 50% Modulation | 22 | 35 | – | dB |
| IF Input Voltage Range | – | 1.0–1000 | – | mV |
| IF Input Resistance Range | – | 10 to 50 | – | kΩ |
| IF Amplifier Transconductance | – | 9.6 | – | mS |
| IF Detector Circuit Impedance | – | 8.3 | – | kΩ |
| Input AGC Threshold | – | 5.0 | – | mV |
| Stop–Sense Output Range | – | 2.2 to 4.0 | – | V |
| Audio Output Impedance at 1.0 kHz (Pins 7 and 14) | – | 300 | – | Ω |
| Stereo Indicator Lamp Leakage | – | – | 1.0 | μA |
| Stereo Indicator Saturation Voltage @ 3.0 mA | – | – | 200 | mVdc |
| Oscillator Capture Range | – | ±3.0 | – | kHz |

9

**Figure 2. MC13122 Test Circuit**




9

# MC13027 MC13122

## AMAX STEREO CHIPSET

### What is AMAX?

In 1993, a joint proposal by the EIA (Electronic Industries Association) and the NAB (National Association of Broadcasters) was issued. It included a unified standard for pre–emphasis and distortion for broadcasters as well as a set of criteria for the certification of receivers. The purpose of this proposal was to restore quality and uniformity to the AM band and to make it possible for the consumer to receive high quality signals using the AM band. The FCC has been supportive of this initiative and has required all new broadcast licensees to meet AMAX standards. The NAB and EIA have continued to encourage receiver manufacturers by offering the AMAX certification logo to be displayed on all qualifying radios. This logo is shown below.

or

### The Receiver Criteria

An AMAX receiver must have wide bandwidth: 7.5kHz for home and auto, 6.5 kHz for portables. It must have some form of bandwidth control, either manual or automatic, including at least two bandwidth provisions, such as "narrow" and "wide". It must meet NRSC receiver standards for distortion and deemphasis. It must have provisions for an external antenna. It must be capable of tuning the expanded AM band (up to 1700 kHz). And finally, home and auto receivers must have effective noise blanking. All of these requirements, except the noise blanking, have been met by Motorola's previous AM radio products, such as MC13025 Front End and the MC13022A C–QUAM stereo decoder. It is the Noise Blanker requirement which is met by the two devices on this data sheet, the MC13027 and MC13122.

Noise blanking, especially in AM auto radios, has become extremely important. The combination of higher energy ignitions, using multiple spark coils, along with increased use of plastic in the auto body, have increased the noise energy at the radio. Also, the consumer has learned to expect higher quality audio due to advances in many other media. For the AM band to sustain interest to the consumer, a truly effective noise blanker is required.

The block diagram below shows the Motorola AMAX stereo chipset. It offers a two–pronged approach to noise blanking which is believed to be the most effective yet offered in the consumer market. The initial blanking takes place in the output of the mixer, using a shunt circuit triggered by a carefully defined wideband receiver. For most noises, some residual audible disturbance is almost always still present after this process. The disturbance becomes stretched and delayed as it passes through the rest of the selectivity in the receiver. The stretching and delay are predictable, so the MC13027 can provide a noise blanking pulse with the correct delay and stretch to the output stages of the MC13122 decoder. The MC13122 has a Track and Hold circuit which receives the blanking signal from the Front End and uses it to gently hold the audio wherever it is as the pulse arrives, and hold that value until the noise has passed. The combined effect is dramatic. A wide range of types of noise is successfully suppressed and the resulting audio seems almost clean until the noise is so intense that the blanking approaches full–time.

The amount of extra circuitry to accomplish noise blanking is relatively small. The external components for this added capability are shown in Figure 3. In the MC13027 Front end, the noise receiver/detector requires two capacitors. The presettings for blanking timing and blanking delay require three external fixed resistors. Finally the decoder requires two track and hold capacitors to store the "audio" voltage during the track and hold function.

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**Figure 3. AMAX Stereo Receiver with Noise Blanker**

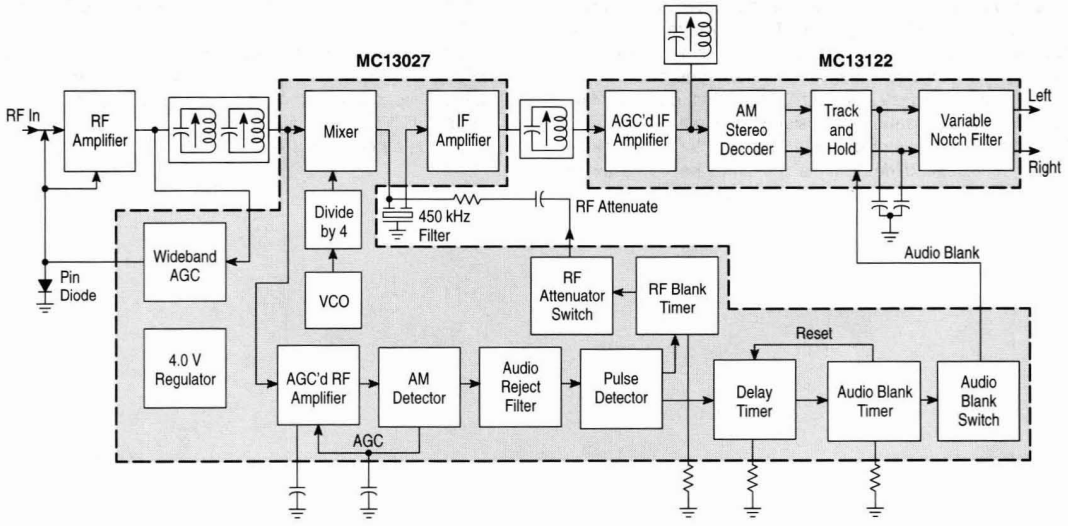
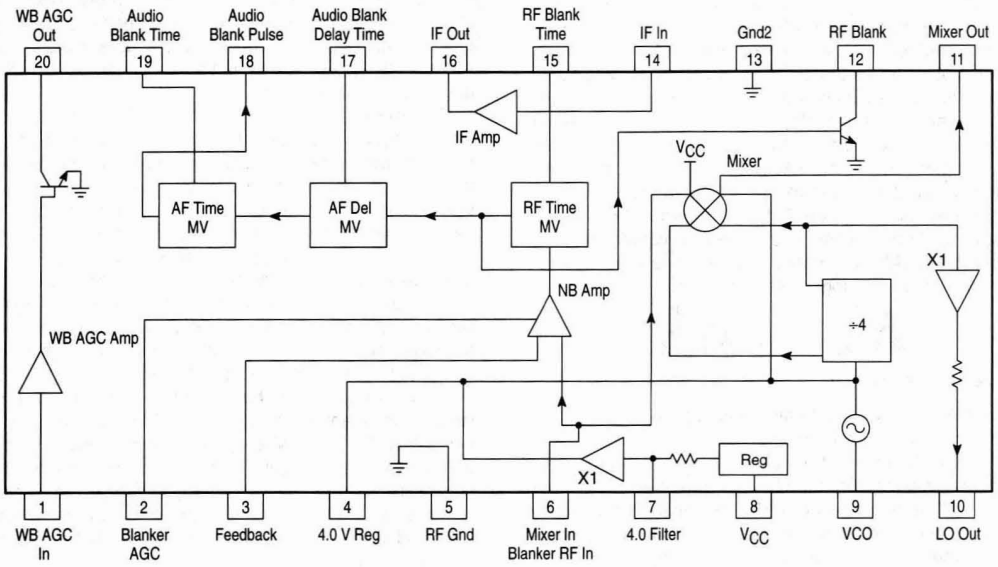


**Figure 4. MC13027 Internal Block Diagram**




## MC13027 FUNCTIONAL DESCRIPTION

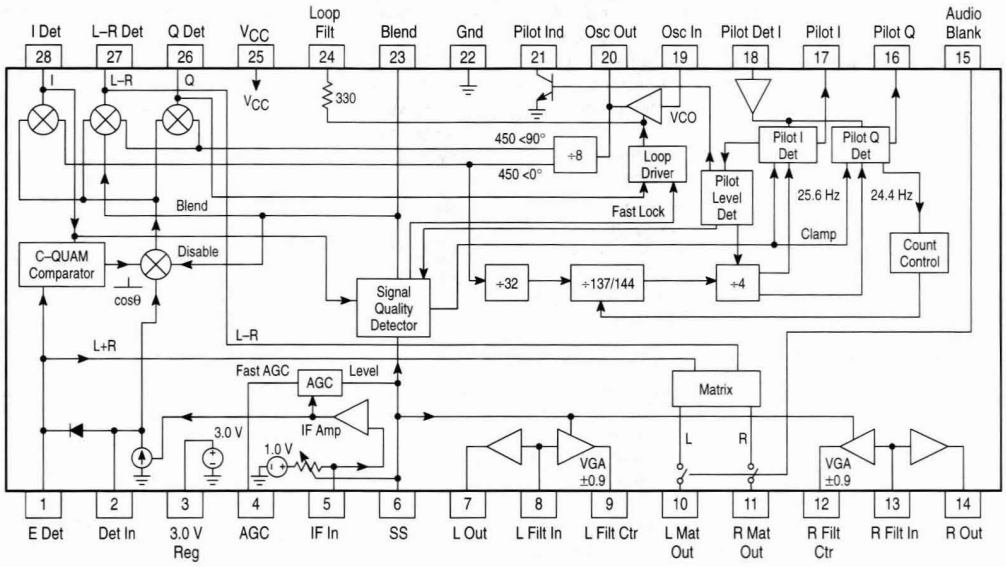
The MC13027 contains the mixer, wide band AGC system, local oscillator, IF pre–amplifier and noise blanker for an AM radio receiver. It is designed to be used with the MC13122 to produce a complete AM stereo receiver. The VCO runs at 4 ($F_{in}$+$F_{IF}$) and is divided internally by 4 for the mixer input and local oscillator buffered output. Dividing the VCO reduces the phase noise for AM stereo applications.

The noise blanker input is connected in parallel with the mixer input at Pin 6. The noise blanker circuitry contains a high gain amplifier with its own AGC so it remains linear throughout the mixer's linear range. It can detect noise pulses as low as 120 μV and generates three pulses when the noise threshold is exceeded. The width and timing of the blanking pulses is set by the resistors connected to Pins 15, 17 and 19. The resistor on Pin 15 sets the length of the RF blanking pulse and determines the time the transistor on Pin 12 is "on". The audio blanking pulse delay is set by the resistor on Pin 17 and the width by the resistor on Pin 19. This is necessary because the IF filtering delays and stretches the noise as it arrives at the detector. The transistor on Pin 18 goes "on" to cause noise blanking in the track and hold circuit in the MC13122 (Pin 15).

Wideband AGC is used in auto receivers to prevent overload – it drives the base of a cascode transistor RF amplifier and also a pin diode at the antenna (See Figures 6 and 7).

A low gain IF amplifier between Pins 14 and 16 is used as a buffer amplifier between the mixer output filter and IF filter. The input resistance of the IF amplifier is designed to match a ceramic IF filter. The gain of the IF amplifier is determined by the impedance of the load on Pin 16.

**Figure 5. MC13122 Internal Block Diagram**




## MC13122 FUNCTIONAL DESCRIPTION

The MC13122 is designed to accept a 450 kHz C–QUAM input signal from approximately 1.0 mV to 1.0 V and produce L and R audio output signals. It has additional features: stop signal, variable bandwidth IF and audio response, stereo indicator driver and track and hold noise blanking.

The IF amplifier on Pin 5 has its own AGC system. It operates by varying the input resistance on Pin 5. With weak signals below approximate 5.0 mV, the input resistance is very high and the amplifier is at maximum gain. For this AGC to be effective, it is necessary to feed the IF input signal from a relatively high impedance. The input resistance variation also reduces the Q of the coil (T1 in the application) so the receiver bandwidth is narrow for weak signals and wide for strong signals. The value of the input resistor (R5) is selected for the desired loading of the IF coil. The impedance of the IF coil on Pin 2 determines the IF gain. Pin 2 is also the input to the C–QUAM decoder.

The IF signal drives the envelope (E), in–phase (I), quadrature (Q) and (L–R) detectors. The E detector is a quasi–synchronous true envelope detector. The others are true synchronous detectors. The E detector output provides the L+R portion of the C–QUAM signal directly to the matrix. The AGC signal of the IF amplifier drives the signal strength output at Pin 6. An external resistor on Pin 6 (sets the gain of the AGC). The Pin 6 voltage is used to control the Q of the audio notch filter, causing the audio bandwidth and depth of the 10 kHz notch to change with signal strength. It is also used as one of the inputs to the signal quality detector which generates the stop–sense and blend signal on Pins 6 and 23 respectively and tells the signal quality detector that the RF input is below the AGC threshold.

### VCO

The 3.6 MHz ceramic resonator on Pins 19 and 20 is part of a phase locked loop which locks to the 450 kHz IF signal. The 3.6 MHz is divided by 8 to produce in–phase and quadrature signals for the I, Q and L–R detectors. It is also divided by 32, and 137/144 to provide signals for the pilot I and Q detectors. The pilot detector is a unique circuit which does not need filtering to detect the 25 Hz pilot.

### Blend Circuit

The purpose of the blend circuit is to provide an AM stereo radio with the capability of very fast lock times, protection against stereo falsing when there is no pilot present and control of the L–R signal so as to provide as much stereo information as possible, while still sounding good in the presence of noise or interference. The circuit also provides an optional stop–sense usable by a radio with seek and/or scan. The stop–sense signal provides a "stop" signal only when the radio is locked on station, signal strength is above minimum level, and the level of interference is less than a predetermined amount. The last feature prevents stopping on frequencies where there is is a multiplicity of strong co–channel stations. It is common for AM radios without this capability to stop on many frequencies with unlistenable stations, especially at night.

The blend circuit controls the PLL fast lock, pilot detector, IF amplifier AGC rate, decoder L–R gain, cosθ compensation and stop–sense as a function of the voltage on a signal external blend capacitor. Timing is determined by the rate of change of voltage on the blend cap. Timing is changed by varying charge and discharge current and pulled down by a current source, switch, and optionally an external switch. The current sources and switches are controlled by various measures of signal quality, signal strength, and presence or absence of pilot tone.

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### Detectors

In AM stereo operation, the Q detector delivers pilot signal via an external low–pass filter to the pilot detector input (Pin 18). The E and I detectors drive the C–QUAM comparator. The L–R signal and the output of the envelope detector are combined in the matrix to produce the L and R signals. The C–QUAM system modifies the in–phase and quadrature components of the transmitted signal by the cosine of the phase angle of the resultant carrier, for proper stereo decoding. An uncompensated L–R would be distorted, primarily by second harmonics. Where there is noise or interference in the L–R, it has been subjectively determined that reducing the cosθ compensation at the expense of increased distortion sounds better than full decoding. The blend line operates over a small voltage range to eliminate cosine compensation.

### Signal Quality Detector – Blend Voltage Control

The signal quality detector output is dependent on signal strength, over–modulation, and whether or not the blend pin has been pulled low prior to searching. Over–modulation usually occurs when a radio is tuned one channel away from a desired strong signal, so this prevents stopping one channel away from a strong signal.

In a radio tuned to a strong, interference free C–QUAM station, the blend voltage will be approximately 3.6 V. In the presence of noise or interference, when the modulation envelope is at a minimum, it is possible for the I detector to produce a negative, or below zero carrier signal. The Signal Quality Detector produces an output each time the negative I exceeds 4%. The output of the detector sets a latch. The output of the latch turns on current source which pulls down the voltage of the blend cap at a predetermined rate. The latch is then reset by a low frequency signal from the pilot detector logic. This produces about a 200 mV change each time 4% negative I is detected. Tables 1 and 2 describe the blend behavior under various conditions.

When the blend voltage reaches 2.2 V a blend control circuit starts to reduce the amplitude of the L–R signal fed to the decoder matrix. By 1.5 V the L–R has been reduced by about 40 dB. At lower voltages it is entirely off and the decoder output is monaural. This reduction of L–R signal, or blend as it is commonly called when done in FM stereo radios, reduces undesirable interference effects as a function of the amount of interference present.

### Stop–Sense

Stop–sense is enabled when the blend voltage is externally pulled below 0.45 V. An input from the AGC indicating minimum signal, or detection of 10% negative I will cause the stop–sense pin to be pulled low. With signals greater than the AGC corner and less than 10% interference the stop–sense will be a minimum of 1.0 V below the 3.0 V line. Very rapid scanning is possible because the radio can scan to the next frequency as soon as the stop–sense goes low. The maximum wait time, set by the radio, is only reached on good stations.

The decoder will not lock on an adjacent channel because it is out of the lock range of the PLL. The beat note produced in the I detector by the out of lock condition will trigger the 10% negative I detector.

### Sequence For Seek Scan

- Change Station – Pull–Down Blend
- Wait Approximately 50 ms for Synthesizer and Decoder PLL to Lock
- Observe Pin 6 Voltage
- If it is Above 2.0 V and Stays Above 2.0 V for Approximately 800 ms, Stay on the Station
- No IF Count Now Needed
- No AGC Level Detector Needed

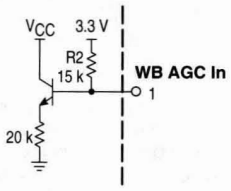
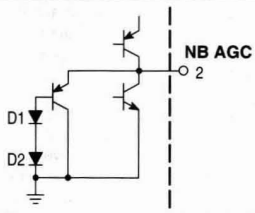
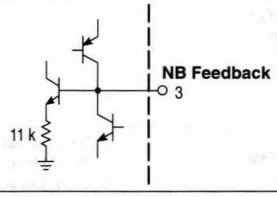
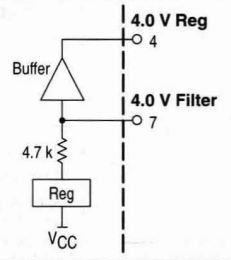
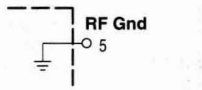
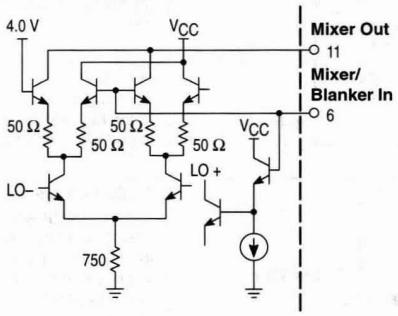
**Table 1. Normal Sequence When Changing Stations**

| | |
|---|---|
| External Pull–Down of Blend Capacitor to Under 0.47 V | – Increased Current Supplied to Loop Driver for Fast Lock<br>– Fast AGC Activated<br>– Extra Current Pull–Up Activated on Blend Capacitor<br>– Pilot Detector Disabled<br>– Loop Locks<br>– Stop–Sense Activated |
| Blend Released | – Blend Capacitor Pulled Up to 0.7 V – Stops<br>– Fast Lock Current Removed<br>– Fast AGC Turned Off<br>– Pilot Detector Enabled |
| Pilot Detected | – Stereo Indicator Pin Pulled Low<br>– Blend Voltage Pulled Positive Rapidly |
| Blend Voltage Reaches 1.4 V | – Audio Starts Into Stereo<br>– 10% Negative I Detector Enabled |
| Blend Voltage Reaches 2.2 V | – Stereo Separator Reaches 20 to 25 dB<br>– Rapid Current Pull–Up Turned Off<br>– 4% Negative I Detector Enabled |
| Blend Voltage Reaches 3.0 V | – cosθ Enabled – Full C–QUAM Decoding<br>– Blend Voltage Continues to Rise to 3.6 V and Stops |

**Table 2. Operation In Adverse Conditions**

| | |
|---|---|
| 4% Negative I Detected | – Blend Pulls Down Approximately 200 mV for Each Event – Acts Like One–Shot<br>– Stops at 2.2 V – cosθ Has Been Defeated, Almost Full Stereo Remains |
| 10% Negative I Detected | – Blend Pulls Down 200 mV for Each Event<br>– Stops at 1.4 V – Stereo Has Blended to Mono<br>– Resets Fast Pull–Up if Blend Has Not Been Above 2.2 V |
| 50% Negative I Detected (Out of Lock) | – Blend Pulls Down Fast During Event<br>– Stops at 0.47 V<br>– Resets Fast Pull–Up<br>– Pilot Indicator Turned Off |
| Minimum Signal Level Detected | – Resets Fast Pull–Up<br>– Pulls Down to 0.7 V |

## MC13027 PIN FUNCTION DESCRIPTION

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 1 | WB AGC In |  | **Wideband AGC Input**<br>The input impedance to the WB AGC detector is 15 k and is internally biased so it must be coupled through a capacitor. The threshold can be increased by adding a resistor in series with the input. The WB AGC begins at about 1.0 mV. In car radios, this input should be connected to the collector of the RF amplifier cascode stage through a resistor and capacitor. A 68 pF to ground will prevent undesired high frequency signals from activating the WB AGC and make the sensitivity more uniform across the band. |
| 2 | Blanker AGC |  | **Blanker AGC**<br>The capacitor to ground is the bypass for the noise blanker AGC circuit. The noise blanker can be disabled by grounding this pin. 10 μF is used in the application, but it can be changed to match the time constant of the main IF AGC in the MC13122, Pin 4. |
| 3 | Feedback |  | **Blanker Feedback**<br>This pin is the dc feedback to the input stage of the wide band amplifier. |
| 4 | 4.0 V Reg |  | **4.0 V Regulator**<br>The 4.0 V regulator supplies low impedance bias to many of the circuits in the IC. It should be bypassed to a ground near Pin 5. |
| 7 | 4.0 V Filt | | **4.0 V Filter**<br>The external capacitor works with internal 4.7 k to filter noise from the bandgap regulator. |
| 5 | Gnd |  | **RF Ground**<br>This pin is the ground for the RF section, blanker RF, filters and all radio circuits except the IF. In the PCB layout, the ground pin should be used as the internal return ground in the RF circuits. |
| 6 | $Blk_{RF}/Mix_{In}$ |  | **Mixer Input/Blanker RF Input**<br>The blanker RF input must be biased from the 4.0 V on Pin 4. The mixer input is to two bases of the upper mixer transistors. A low impedance dc path to the 4.0 V on Pin 4 is required. Normally, this would be a coil secondary connected between Pins 6 and 4. |
| 11 | Mixer Out | | **Mixer Output**<br>A single ended output of a double balanced mixer. A load resistor to supply is chosen to match the ceramic filter, typically 1.5 k to 1.8 k. Output current is 830 μA. |

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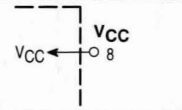
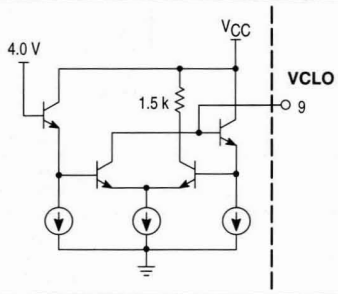
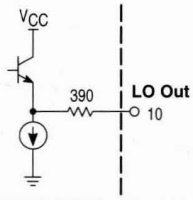
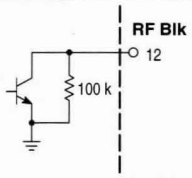
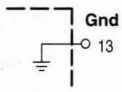
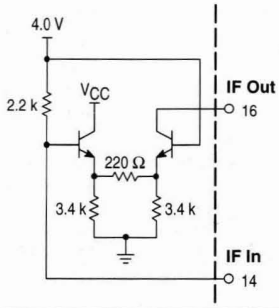
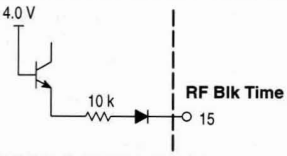
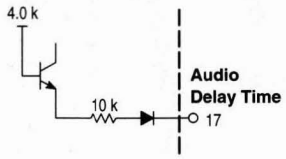
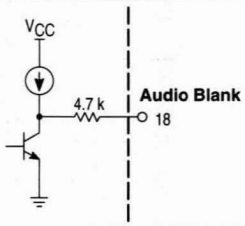
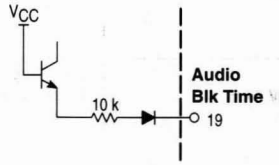
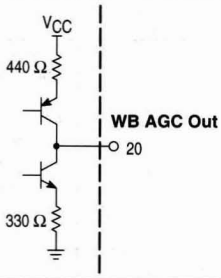
**MC13027 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 8 | $V_{CC}$ |  | **Supply Voltage**<br>The normal operating voltage range is 6.0 to 10 V. |
| 9 | VCLO |  | **Voltage Control Local Oscillator**<br>The oscillator is a cross coupled negative resistance type and this pin must be connected through a low dc resistance to Pin 4, the 4.0 V regulator. Normally, this would be the secondary of the oscillator coil.<br>The impedance of the secondary winding should be around 2.8 kΩ to guarantee that the oscillator will run. It operates at 4 times the LO frequency: $f_{osc} = 4(F_{in}+F_{IF})$. |
| 10 | LO Out |  | **Local Oscillator Output**<br>This is an emitter follower for LO output to drive a synthesizer. It is a square wave output, the internal series resistance and allows a small bypass to reduce high frequency harmonics. |
| 12 | RF Blank |  | **RF Blanker**<br>An unbiased NPN acts as a SHUNT impedance when turned on. The 100 k resistor provides a dc path for the capacitor. |
| 13 | Gnd2 |  | **IF Ground**<br>Pin 13 is the ground for the IF section and the timing and switching circuits in the blanker.<br>In the application circuit this should be common to the MC13122 ground. |
| 14 | IF In |  | **IF Input**<br>A degenerated differential amplifier internally biased to 4.0 V. The IF input impedance is approximately 1.8 k to match a ceramic filter. The IF amplifier is used as a buffer between the ceramic filter and the detector coil and has a fixed gain determined by the impedance of the output coil. |
| 16 | IF Out | | **IF Output**<br>An open collector provides high–impedance drive to the MC13122; the IF gain is set by the ac impedance on this pin. |
| 15 | RF Time |  | **RF Blank Time**<br>A resistor to ground sets the RF blanking time. The time is set to the minimum required to attenuate the pulse received. This is normally longest at the low end of the band. The value is best approved by ear. A fixed value can be chosen for production. (50 μs is typical.) |

**MC13027 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 17 | Delay Time |  | **Audio Blank Delay Time**<br>A resistor to ground sets the delay time from the beginning of the RF blanking pulse to the beginning of the audio blanking pulse. This normally is about 50 μs for a wide AMAX filter. The ear is the most sensitive measure of the correct delay; start low, say 20 μs, and vary delay until noise is heard, and then reduce somewhat. |
| 18 | Audio Blank Cntl |  | **Audio Blank Pulse**<br>When the blanker is operating, a positive pulse from this pin is fed to Pin 15 of the MC13122 to blank the audio signal. |
| 19 | Audio Time |  | **Audio Blank Time**<br>A resistor to ground sets the width of the blanking pulse on Pin 18. This is usually selected by applying a pulse to the antenna of the receiver and adjusting a variable resistor. The blanking signal should be just long enough to suppress the audio pulse. Again the ear is the most sensitive tool. Start long, approximately 250 μs and reduce until noise is audible then increase. |
| 20 | WB AGC Out |  | **Wideband AGC Output**<br>A push–pull current output. The resistor to voltage source (normally $V_{CC}$) determines the gain. Used to bias a cascode transistor in series with the input FET and can also be used to drive a PNP transistor which drives a pin diode attenuator (refer to Application Circuit Figure 6.) |

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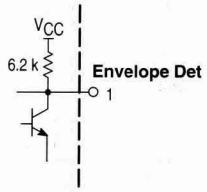
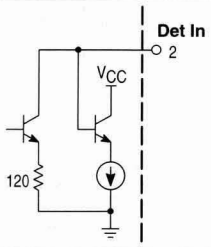
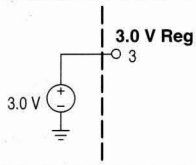
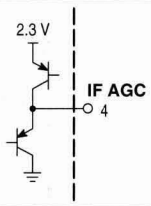
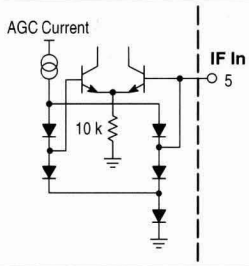
## MC13122 PIN FUNCTION DESCRIPTION

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 1 | E Detector |  | **Envelope Detector**<br>This is the output of the envelope detector and is used for one input to the comparator that generates cosθ signal and the L+R input to the matrix. It is a quasi–synchronous full wave detector with very low distortion (<1% at 100% modulation). The output impedance is 6.2 k, and it is bypassed to $V_{CC}$ with 1.0 nF to eliminate 900 kHz components. The bypass capacitor must be the same as the one on Pin 27 and 28 for lowest stereo distortion and best separation. |
| 2 | Detector In |  | **IF Out/Decoder Input**<br>The IF coil is connected from Pin 2 to Pin 3, the 3.0 V regulator. The IF amplifier output is a current source. The gain is determined by the impedance between Pins 2 and 3. Bandwidth and gain is set by the resistance across the coil. |
| 3 | 3.0 V Reg |  | **3.0 V Regulator**<br>This bandgap regulator supplies bias to many of the circuits in the IC. |
| 4 | AGC Byp |  | **IF AGC Bypass**<br>The AGC has a fast and slow time constant. The fast AGC is 18X the slow one and is active when the 450 kHz loop is not locked. This allows for fast scanning in car radios. This capacitor should be selected for distortion for low frequencies at 80% modulation. |
| 5 | IF In |  | **IF Input**<br>The IF AGC varies the current through attenuator diodes. The diodes vary the input impedance shunting the IF signal. The varying impedance also varies the Q and therefore the bandwidth. The IF AGC is accomplished by turning on the diodes and lowering the IF input impedance. |

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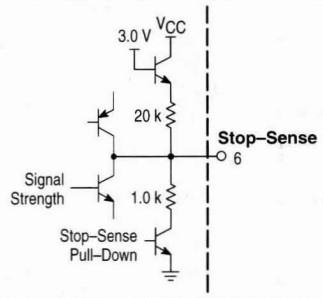
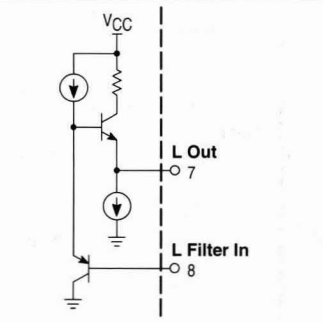
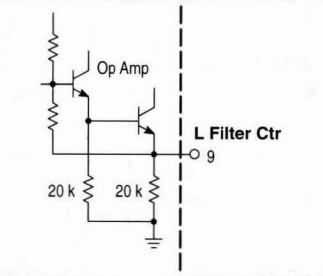
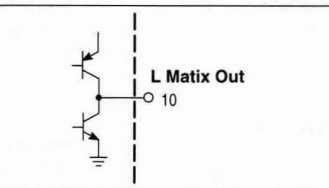
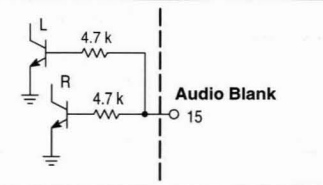
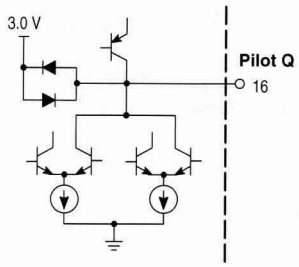
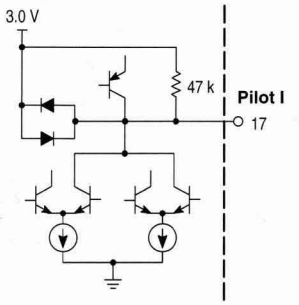
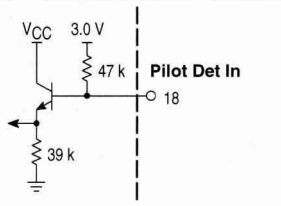
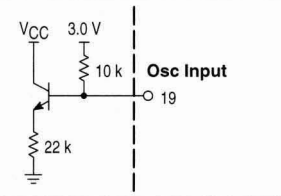
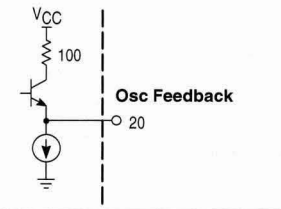
**MC13122 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 6 | SS |  | **Signal Strength/Stop–Sense**<br>The signal strength is a push–pull circuit. The voltage is 2.2 V at minimum signal and 3.5 to 5.0 V at strong signal. This dc voltage is also used to control the audio output notch filters. If the Blend pin is low the stop–sense is activated and this pin can go low. This can be used to control the seek–scan in the radio. |
| 7<br>14 | Left Out<br>Right Out |  | **Filtered Left and Filtered Right Output**<br>This can drive a de–emphasis filter to bring audio contour to AMAX specifications. Since the output is an emitter follower, the output impedance is low, and a series R should be used with the de–emphasis network as shown on the application circuit. |
| 8<br>13 | L Filt In<br>R Filt In | | **Input to Notch Filter**<br>DC bias is supplied through the external filter components. |
| 9<br>12 | L Filt Ctr<br>R Filt Ctr |  | **Left Filter and Right Filter Center**<br>Drives the center leg of a twin–T filter, varying the Q. At strong signal, positive feedback narrows the notch, and there is little HF roll–off. At weak signal, negative feedback produces a broad notch and HF roll–off. |
| 10<br>11 | L Matrix Out<br>R Matrix Out |  | **Track and Hold Output**<br>This is a unity gain operational amplifier output. The current is turned off by the blanking pulse. The capacitor holds output voltage constant until unblanked. Internal feedback causes the output impedance to be low. |
| 15 | AF Blank In |  | **Audio Blank Control**<br>The current to the output drivers is turned off. |

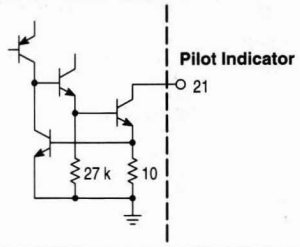
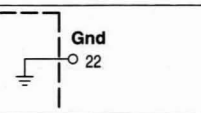
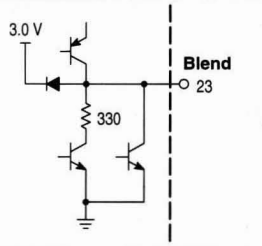
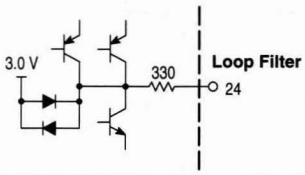
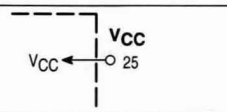
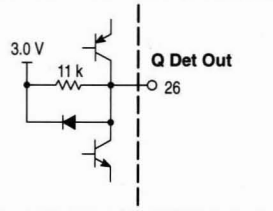
9

**MC13122 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 16 | Pilot Q |  | **Pilot Q**<br>This is the output of a quadrature detector of a narrowband phase locked loop system.<br>It is used to control the pilot detector circuitry. The pilot Q is clamped to the 3.0 V reference when the blend voltage is pulled low. This results in faster pilot detection when a stereo station is tuned in. If the blend is not pulled low, the pilot Q will drift up approximately 0.5 V when there is no pilot, and it will take longer to detect the pilot. The capacitor to ground is the loop filter. It sets the pilot loop bandwidth: if it is too large, the loop bandwidth maybe too small, and the pilot may not be re–acquired if it is lost unless the blend pin is externally pulled low again. |
| 17 | Pilot I |  | **Pilot I**<br>When the loop is locked to a 25 Hz AM stereo pilot, this is the output of a an in–phase synchronous detector. The capacitor filters the output, which is used to drive the pilot indicator driver on Pin 21. The time constant for the pilot indicator output is determined by this capacitor and the internal 47 k resistor. If the capacitor is too small, it can lead to pilot falsing due to noise. If the capacitor is too large, the acquisition time increases. The cap is charged to 3.0 V when the blend voltage is low to shorten lock time. |
| 18 | Pilot Det In |  | **Pilot Detector Input**<br>The pilot detector will detect a pilot tone between 24.4 and 25.6 Hz. The pilot signal is fed from Q detector through a low pass filter on Pin 26. The audio signals from the Q detector must be filtered out, so a low–pass filter is used. The capacitor in series with Pin 18 blocks dc and prevents large low frequency transients from knocking the decoder out of stereo mode. |
| 19 | Osc In |  | **Oscillator Input**<br>The input impedance is 10 k, but the recommended circuit adds 3.9 k in parallel with this to control the capture range of the VCO to be around ±3.0 kHz. using the recommended ceramic resonator. |
| 20 | Osc Out |  | **Oscillator Output**<br>The internal phase shift of the VCO is 90 degrees, and the output impedance is low. It is designed to drive a resonant circuit with a 90 degree phase shift at the center frequency. |

9

**MC13122 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 21 | Pilot Indicator |  | **Pilot Indicator**<br>The maximum current is internally limited to protect the IC, but it should be operated with a current limiting resistor. |
| 22 | Gnd |  | **Ground**<br>Use good practices to keep oscillator returns and RF bypasses to good copper near this point |
| 23 | Blend Cont |  | **Blend Control**<br>There are pull–up and pull–down currents provided to this pin. The external capacitor controls the rate of change of this voltage and 22 μF is recommended. This is an important voltage affecting many functions in the IC. |
| 24 | Loop Filt |  | **Loop Filter**<br>The phase detector is a current source, so only a single RC loop filter is needed for a second order loop. The internal 330 Ω resistor together with a 47 μF gives the correct corner frequency and damping for the proper operation on the decoder loop. The cap should be low leakage to avoid static phase error. |
| 25 | $V_{CC}$ |  | **$V_{CC}$**<br>The operating voltage is normally 8.0 to 10 V in car radios. The MC13122 will work from 6.0 to 10 V. |
| 26 | Q Detector |  | **Q Detector Output**<br>This is a synchronous detector in quadrature with the 450 kHz IF signal. The output impedance is 11 k. This signal is normally used for input to the pilot detector and internally for the fast lock. |

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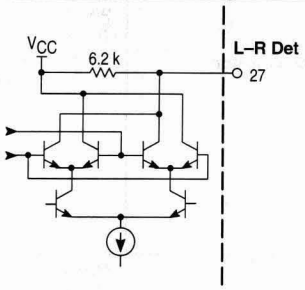
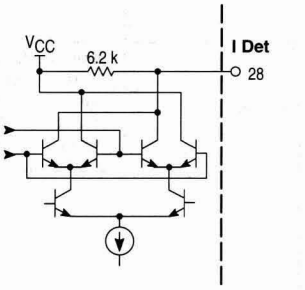
**MC13122 PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Internal Equivalent Circuit | Description |
|---|---|---|---|
| 27 | L–R Detector |  | **L–R Detector**<br>This is similar to the Q detector output but its level is controlled by the blend circuit. When the blend is active, the L–R output is reduced in level by reducing the dc current until mono operation is reached. It operates in the same way as the blend circuit in FM stereo decoders. The bypass capacitor should be 1.0 nF as on Pin 1 for optimum channel separation. |
| 28 | I Detector |  | **I Detector**<br>This is a synchronous detector in phase with the 450 kHz IF signal. It is used internally to generate the cosθ signal and as an input to the signal quality detector. The bypass capacitor should be the same as the one on Pin 1 for best separation and lowest stereo distortion. |

9

## CAR RADIO APPLICATION

Figure 6 shows a car radio circuit using a TOKO pre–tuned RF module. The RF module includes a 4 diode tracking circuit to eliminate mistracking between the oscillator and RF circuits over the 530 to 1700 kHz AM band. This is important for stereo performance because mistracking will cause mono distortion and will significantly reduce the stereo separation. The THB122 module contains the variable 10 kHz notch filter. This module can be replaced with discrete components as shown in Figure 8, using 1% resistors and 5% capacitors.

Some manufacturers add a PIN diode attenuator at the antenna input. An example is shown in Figure 7.

The WB AGC sensitivity can be adjusted by changing R4 in series with the WB AGC input, Pin 1. The internal input resistance is 15 k.

R15, R17 and R19 are the blanker timing resistors. They were setup for this circuit and can be changed if desired.

FL1 is a linear phase IF filter . We recommend a Gaussian (rounded) filter, such as SFG or SFH for lower distortion and better separation than one with a flatter amplitude response. The SFG types of filters have poorer selectivity than the ones with flat GDT (group delay time) so some compromise has been made on adjacent channel selectivity.

The blanker can be disabled for testing by grounding the blanker AGC on Pin 2 in the MC13027.

The blanker and mixer inputs must be biased from the 4.0 V regulator through a low dc resistance like the secondary winding of the RF coil.

The receiver VCO operates at 4 times the local oscillator frequency and is divided internally in the MC13027 so that both the mixer input and the LO out is the same as in other receivers. This receiver can be connected to an existing synthesizer. For AM stereo, the synthesizer must have low phase noise. The Motorola MC145173 is recommended. For bench testing of this receiver, the Motorola MC145151 parallel input synthesizer may be useful. It will operate on 9.0 V and the phase detector can provide tuning voltage without a buffer amplifier.

The SS (stop–sense) output can be used for station searching and scanning. The best way to use it is to connect the SS signal to a comparator or A–D converter in the control microprocessor. If Pin 23 is grounded during searching by turning on Q3, the SS voltage changes from less than 0.5 V to around 2.2 V when an RF threshold is exceeded, as is shown in the graph in Figure 15. This system results in very reliable stopping on usable signals and fast detection of AM stereo signals. After a station is detected, Q3 should be turned off.

This receiver is very easy to set up because the TOKO module is pre–aligned. The only adjustments are to tune T1 and T2 for maximum voltage of the SS out line or maximum audio with a weak signal. If desired, they can be changed slightly to maximize stereo separation.

If different components are used, the blanker resistors can be setup as follows:

Ground Pin 2 of the MC13027. Apply a 1.0 μs pulse or 50 Hz square wave of about 10 mV through a dummy antenna and synchronize an oscilloscope to the pulse generator. Observe the signal at the mixer collector (Pin 11). It should be a sine wave burst. Remove the ground on Pin 2 and adjust R15 so the burst is just suppressed. Check the performance at the ends and middle of the band because the width might change due to RF circuit bandwidth.

Mix the pulse signal with a CW signal of about 300 μV with a power combiner and connect the oscilloscope to Pin 7 or Pin 14 of the MC13122. Adjust R17 so the blanking starts at the beginning of the audio pulse and R19 so the audio blanking is just long enough to suppress the audio pulse. The audio blanking time should not be made longer than necessary because it will be more noticeable in the normal program. The effectiveness of the blanker can be determined in field testing by connecting a switch from Pin 2 of the MC13027 to ground and bringing it outside the radio.

Figures 10 to 19 refer to the performance of the Application Circuit of Figure 6.

**Figure 6. AMAX Chipset Application Circuit**

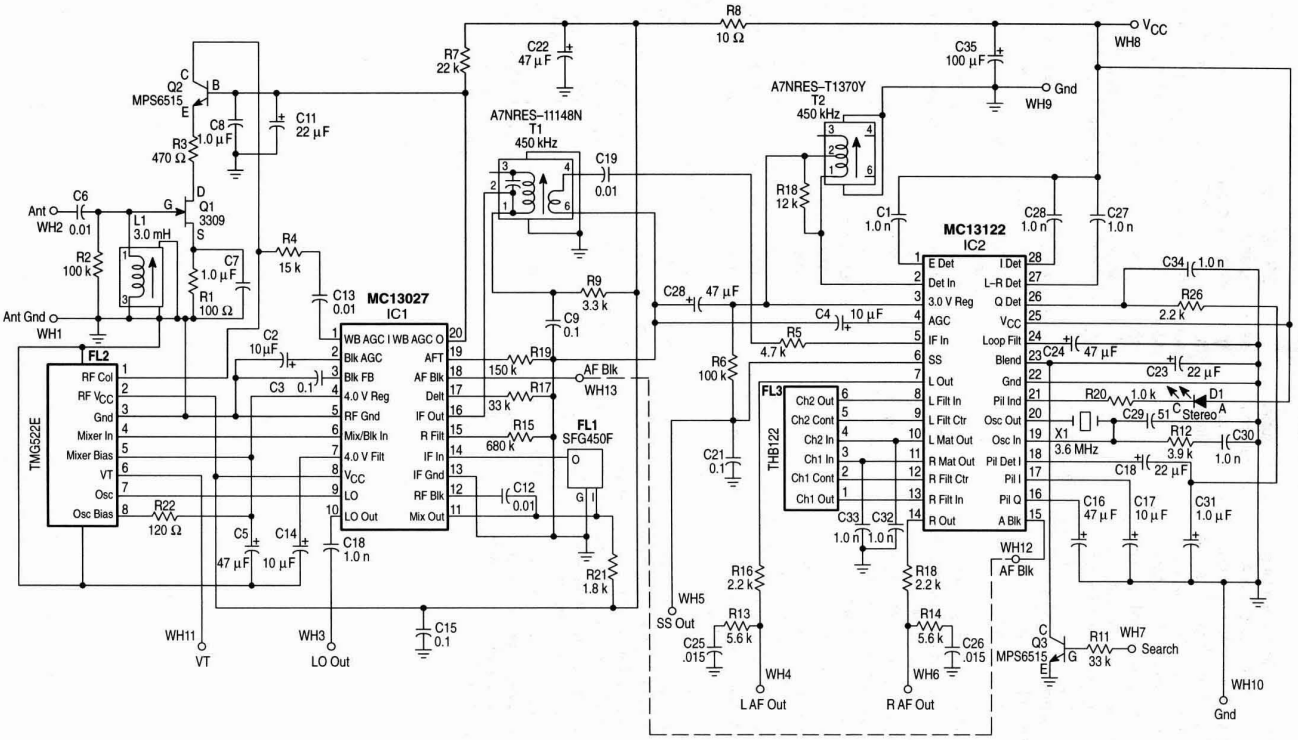


**Figure 7. RF Pin Diode**

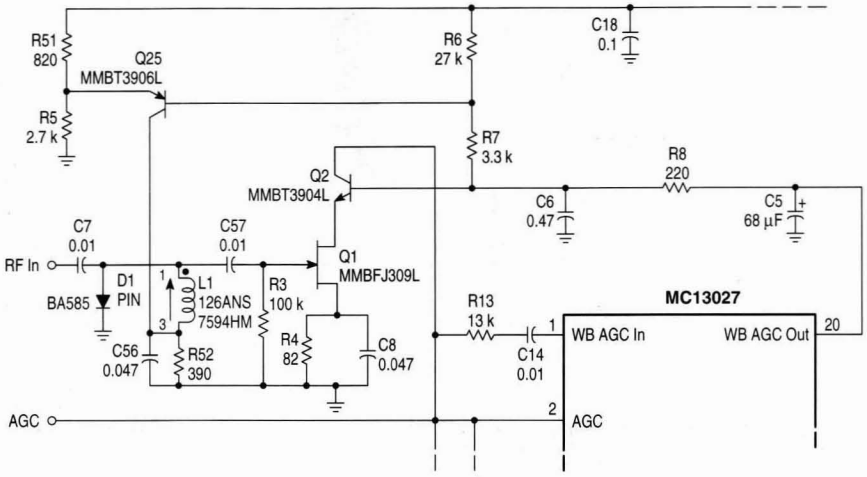



**Figure 8. MC13027/MC13122 Discrete RF and Notch Filters**

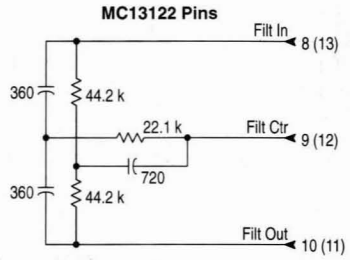
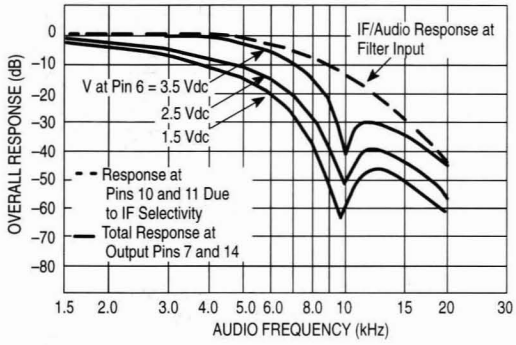
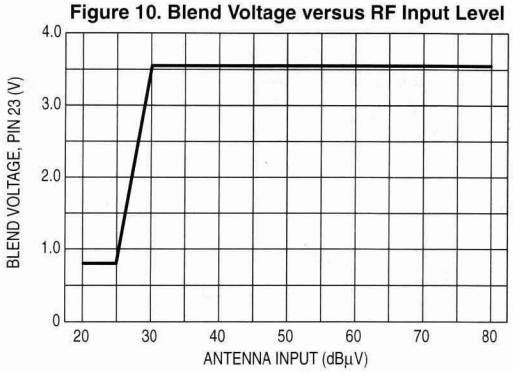



**Figure 9. Overall Selectivity of a Typical Receiver versus Filter Control Voltage**



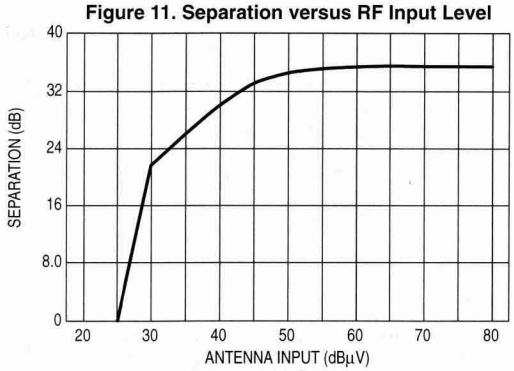

9

**Figure 10. Blend Voltage versus RF Input Level**



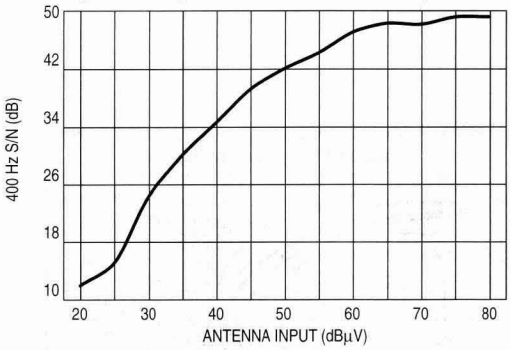

**NOTE:** The graphs on this page were made using the 15/60 pF dummy antenna and the Application Circuit of Figure 6.

**Figure 11. Separation versus RF Input Level**



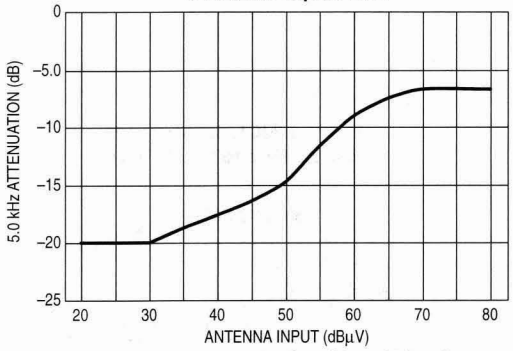

**NOTE:** The radio stays in mono until the stereo signal is sufficiently large and then makes a smooth transition to stereo. This is similar to FM receivers with variable blend.

**Figure 12. Signal to Noise versus RF Input Level**



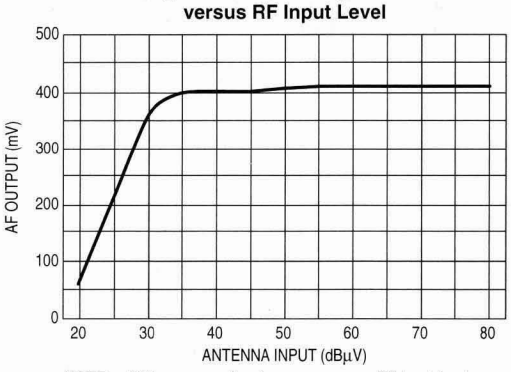

**NOTE:** The slightly abrupt change at around 25 dBμV is due to the decoder switching into stereo.

**Figure 13. 5.0 kHz Attentuation versus RF Input Level**



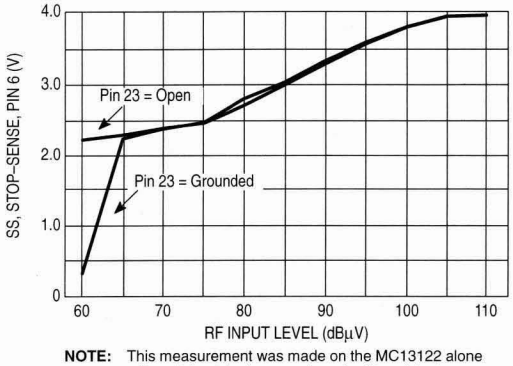

**NOTE:** This curve shows the effect of the variable audio bandwidth control of the MC13122. It is due to the variable loading of the IF coil and the variable 10 kHz notch filter in the output.

**Figure 14. Audio Output Level versus RF Input Level**




**NOTE:** All the curves of performance versus RF input level were generated using the car radio receiver circuit shown in Figure 6. Using a 15/60 pF dummy antenna input and a 50% L only stereo signal.

**Figure 15. Stop–Sense Voltage versus RF Input Level**




**NOTE:** This measurement was made on the MC13122 alone with a 10 k series input resistor. It will enable the designer to determine the stop–sense level if the gain of receiver RF section is known. Note that if Pin 23 is held low, the SS voltage on Pin 6 rises from about 0.3 to 2.2 V over a small change in RF level. This can be used to generate a very reliable stop signal. If Pin 23 is not held low, the SS voltage starts out at 2.2 V and rises slowly to a maximum of around 4.0 V.

**Figure 16. Audio Blanking Delay versus R17**

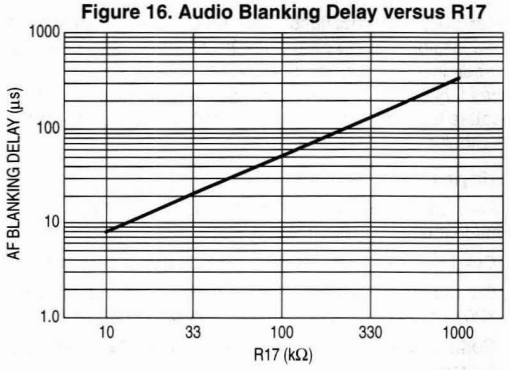



**Figure 17. RF Blanking Time versus R15**

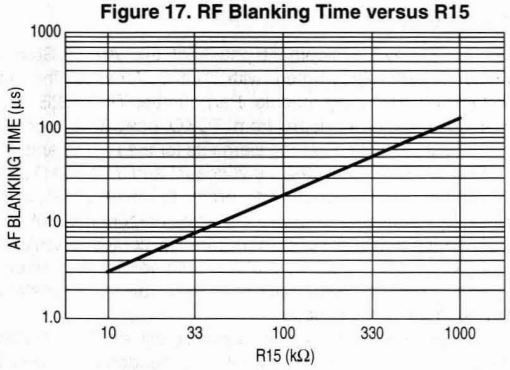



**Figure 18. Audio Blanking Time versus R19**

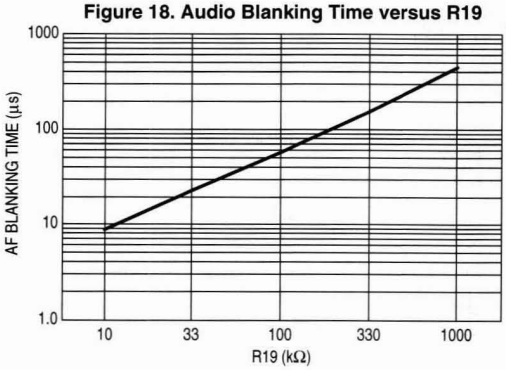
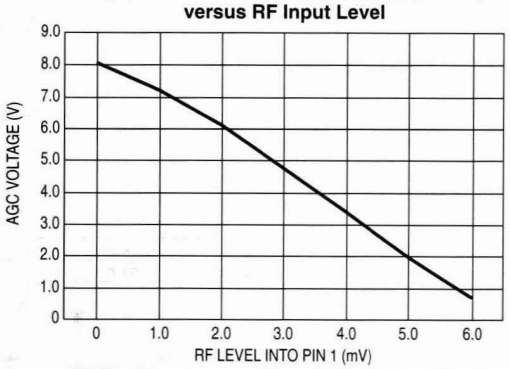



**Figure 19. WB AGC Output Voltage (Pin 20) versus RF Input Level**




**NOTE:** This was measured by applying an RF signal through a capacitor directly to Pin 1. The input resistance is 15 k, so the desired threshold can be increased by adding a resistor in series with the input.

9

## AMAX STEREO CHIPSET

### The RF Module

In the early development phase of this AMAX Stereo Chipset, Motorola worked with TOKO America Inc. to develop an RF tuning module. Part number TMG522E was assigned and is available from TOKO now. This module provides the "tracked" tuning elements for the RF (T1 and T2 and associated capacitors and varicaps) and the VCO (T3 et al). Some radio designers may prefer to develop their own tuning system using discrete coils and components, but the TOKO approach offers good performance, compactness and ease of application. Motorola recommends that every designer use this approach at least for initial system development and evaluation.

As refinement of the application progressed, it was found that a modification of the TMG522E was needed which would reduce the amount of VCO leakage into the Mixer through the power supply connections. This modification is described below. Motorola will work with TOKO to develop a new part number incorporating this change. In the meantime, it is necessary that the user perform these simple changes, because the radio circuits throughout this data sheet assume this modified design.

### Modifying the TMG522E

Referring to Figures 20 and 21, there are three simple steps to the modification:

1. Cut the thin copper trace from Pin 2 to Pin 5 as shown.
2. Cut the thin copper trace from Pin 8 to the bottom of the 120 Ω resistor. Removal of the resistor is optional.
3. Connect a wire from Pin 5 to the top of the 120 Ω resistor (or the upper pad for the resistor).

**Figure 20. TMG522E Schematic**

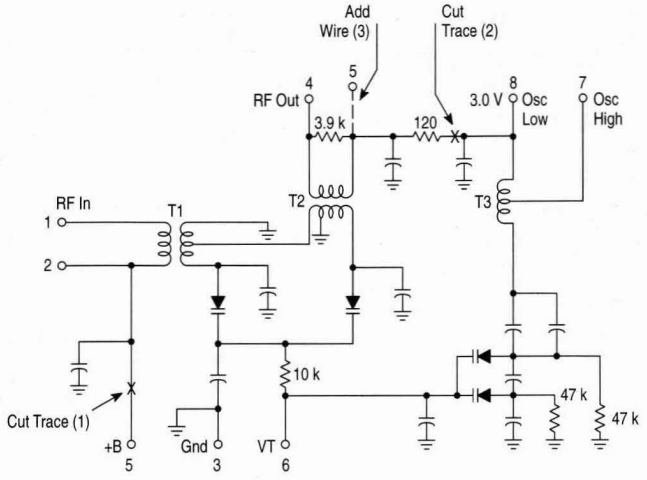
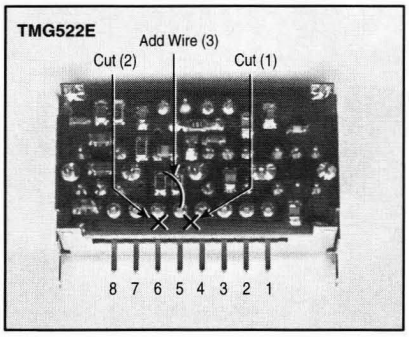



**Figure 21. TMG522E Physical Modifications**



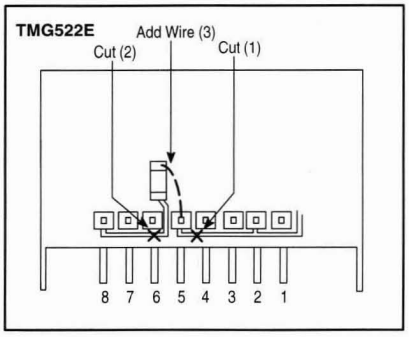



**Figure 22. AMAX Chipset Printed Circuit Board**
(Top View)

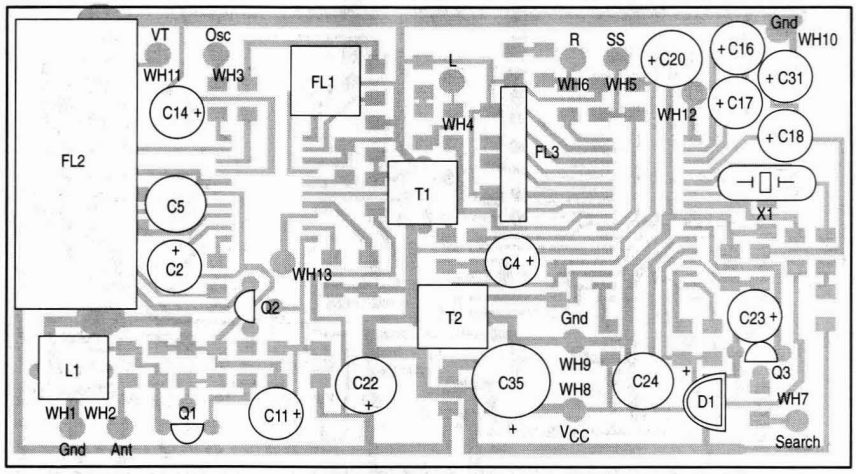



**Figure 23. AMAX Chipset Printed Circuit Board**
(Bottom View)

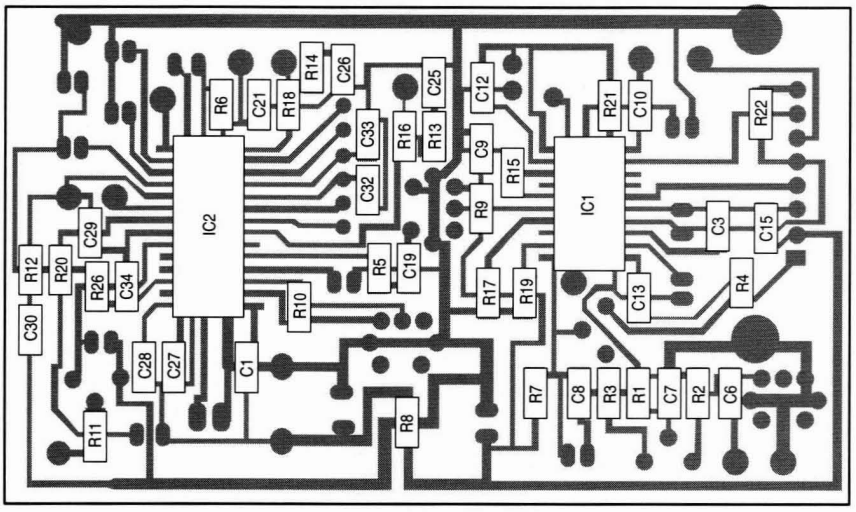



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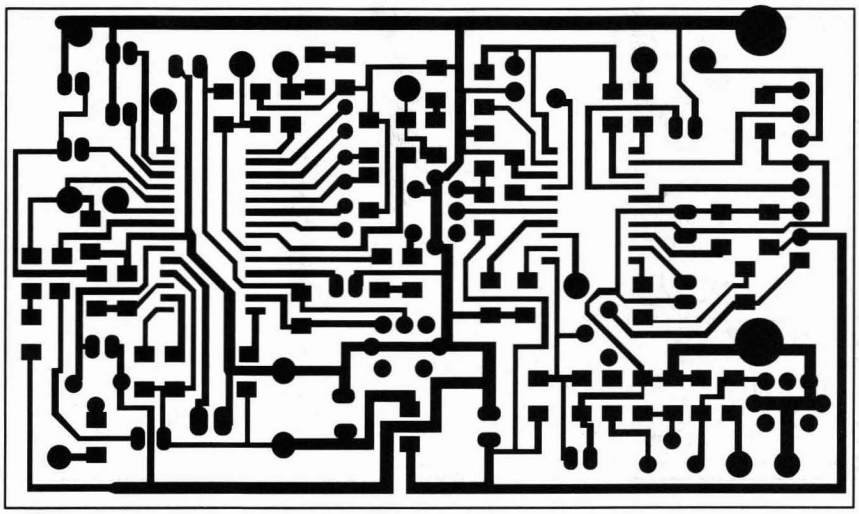
**Figure 24. AMAX Chipset Printed Circuit Board**
(Copper View)



MOTOROLA

# MC13028A

# Advanced Wide Voltage IF and C-QUAM® AM Stereo Decoder

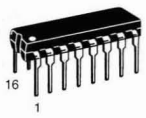
**C–QUAM AM STEREO ADVANCED WIDE VOLTAGE IF and DECODER for E.T.R. RADIOS**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13028A is a third generation C–QUAM stereo decoder targeted for use in low voltage, low cost AM/FM E.T.R. radio applications. Advanced features include a signal quality detector that analyzes signal strength, signal to noise ratio, and stereo pilot tone before switching to the stereo mode. A "blend function" much like FM stereo has been added to improve the transition from mono to stereo. The audio output level is adjustable to allow easy interface with a variety of AM/FM tuner chips. The external components have been minimized to keep the total system cost low.

- Adjustable Audio Output Level
- Stereo Blend Function
- Stereo Threshold Adjustment
- Operation from 2.2 V to 12 V Supply
- Precision Pilot Tone Detector
- Forced Mono Function
- Single Pinout VCO
- IF Amplifier with IF AGC Circuit
- VCO Shutdown Mode at Weak Signal Condition

The purchase of the Motorola C–QUAM® AM Stereo Decoder does not carry with such purchase any license by implication, estoppel or otherwise, under any patent rights of Motorola or others covering any combination of this decoder with other elements including use in a radio receiver. Upon application by an interested party, licenses are available from Motorola on its patents applicable to AM Stereo radio receivers.

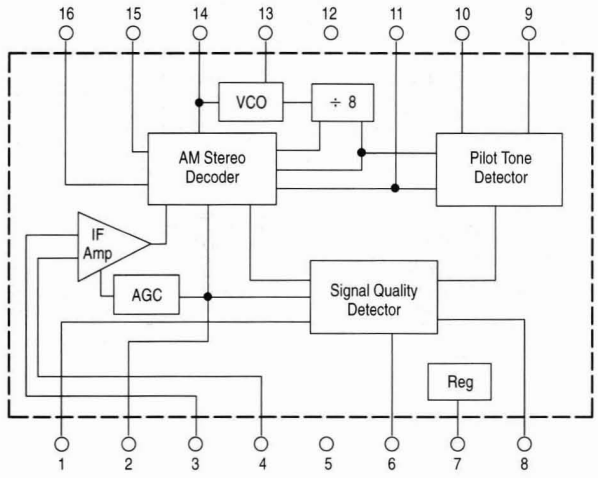



**P SUFFIX**
PLASTIC PACKAGE
CASE 648

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

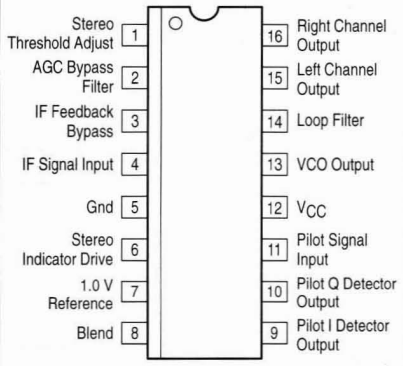
9

**Representative Block Diagram**




This device contains 679 active transistors.

**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13028AD | $T_A = -25°$ to $+70°C$ | SO–16 |
| MC13028AP | | DIP–16 |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 14 | Vdc |
| Operating Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature | $T_A$ | –25 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +150 | °C |
| LED Indicator Current | $I_{LED}$ | 10 | mA |

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 8.0 Vdc, $T_A$ = 25°C, Input Signal Level = 74 dBμV, Modulation = 1.0 kHz @ 50% Modulation, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current Drain | $I_{CC}$ | | | | mA |
| $V_{CC}$ = 2.2 V | | – | 9.0 | 11 | |
| $V_{CC}$ = 8.0 V | | – | 11 | – | |
| Audio Output Level, L+R, Mono Modulation | $V_{out}$ | | | | mVrms |
| $R_O$ = 1.8 k, $V_{CC}$ = 2.2 V, Input 55 dBμV | | 22 | 33 | 44 | |
| $R_O$ = 10 k, $V_{CC}$ = 8.0 V, Input 50 dBμV | | 150 | 200 | 250 | |
| Input 40 dBμV | | 80 | 130 | 180 | |
| Input 31 dBμV | | – | 50 | – | |
| Audio Output Level, L or R Only, Stereo Modulation | $V_{out}$ | | | | mVrms |
| $R_O$ = 1.8 k, $V_{CC}$ = 2.2 V, 55 dBμV Input | | 35 | 80 | 106 | |
| $R_O$ = 10 k, $V_{CC}$ = 8.0 V | | 340 | 460 | 580 | |
| Output THD | | | | | % |
| 50% Stereo, L or R Only | THD1 | – | 0.6 | 1.8 | |
| 50% Mono, L+R | THD2 | – | 0.3 | 0.6 | |
| 90% Mono, L+R, Input 86 dBμV | THD3 | – | – | 1.5 | |
| Channel Separation<br>50% L or R Only | L or R | 23 | 35 | – | dB |
| Decoder Input Sensitivity<br>$V_{out}$ = –10 dB | $V_{in}$ | – | 33 | – | dBμV |
| Force to Mono Mode, (Pin 10) | – | 0.25 | 0.3 | – | Vdc |
| Stereo Threshold Adjust (Pin 1) | $S_{TA}$ | | | | dBμV |
| Pin 1 Open | | – | 50 | 55 | |
| R1 = 15 k (Gnd) | | – | 55 | – | |
| R1 = 680 k ($V_{CC}$) | | – | 48 | – | |
| Signal to Noise Ratio, $R_O$ = 10 k | S/N | | | | dB |
| 50% Stereo, L or R Only | | 40 | 62 | – | |
| 50% Mono, L+R | | 40 | 59 | – | |
| Input Impedance | $R_{in}$ | – | 10 | – | kΩ |
| (Reference Specification) | $C_{in}$ | – | 8.0 | – | pF |
| Maximum Input Signal Level for THD ≤ 1.5% | – | – | – | 86 | dBμV |
| Blend Voltage | BI | | | | Vdc |
| Mono Mode | | 0.7 | – | 0.9 | |
| Stereo Mode | | 1.20 | 1.30 | 1.35 | |
| Out of Lock | | – | 0.12 | 0.2 | |
| VCO Lock Range | $OSC_{tun}$ | – | ±2.5 | – | kHz |
| AGC Range | $AGC_{rng}$ | – | 44 | – | dB |
| Channel Balance | C–B | –1.0 | – | 1.0 | dB |
| Pilot Sensitivity | – | – | 2.5 | 4.0 | % |

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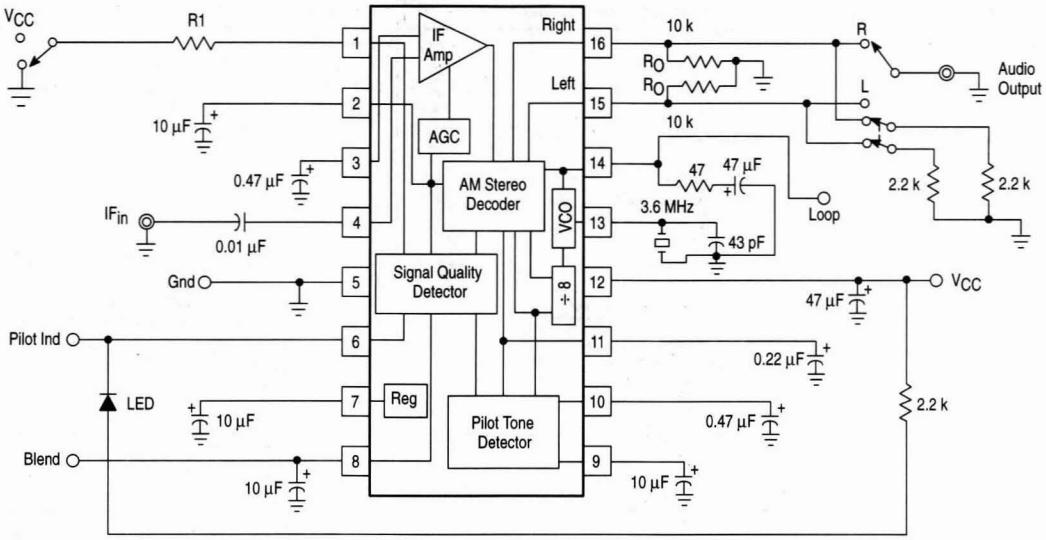
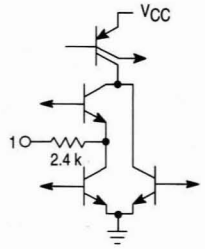
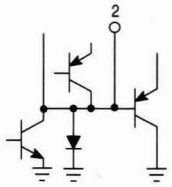
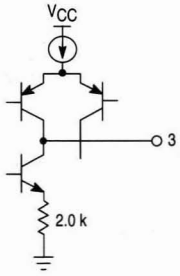
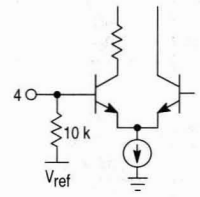
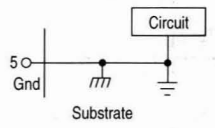
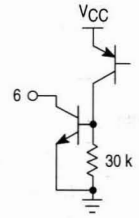
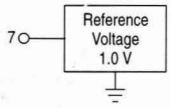
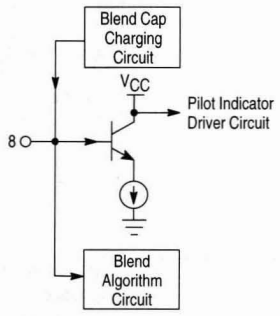
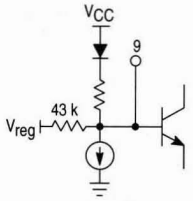
**Standard Test Circuit**




**PIN FUNCTION DESCRIPTION**

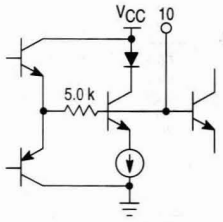
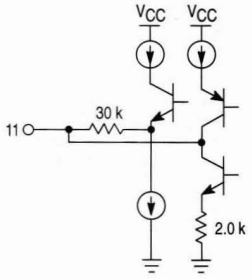
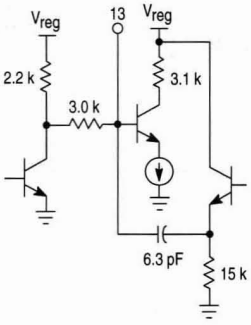
| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 1 | $S_{TA}$ |   | **Stereo Threshold Adjustment Pin** The function of this circuit is to provide the freedom to achieve a desired value of incoming IF signal level which will cause full stereo operation of the decoder. The level can be determined by the value of R1, a resistor from Pin 1 that can be connected to either $V_{CC}$ or to ground. This resistor may also be omitted in some designs (Pin 1 left open). The approximate dc level with the pin left open is 0.6 Vdc. |
| 2 | $AGC_{cap}$ |   | **AGC Filter Bypass Capacitor** An electrolytic capacitor is used as a bypass filter and it sets the time constant for the AGC circuit action. The recommended capacitor value is 10 µF from Pin 2 to ground. The dc level at this pin varies as shown in the curve in Figure 13, AGC Voltage versus Input Level. |
| 3 | $IF_{FBcap}$ |   | **IF Amplifier Feedback Capacitor** A capacitor which is specified to have a low ESR at 450 kHz is normally used at Pin 3. The value recommended for this capacitor is 0.47 µF from Pin 3 to ground. This component forms a low pass filter which has a corner frequency around 30 kHz. |

## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 4 | $IF_{in}$ |  | **IF Amplifier Input**<br>Pin 4 is the IF input pin. The typical input impedance at this pin is 10 k. The input should be ac coupled through a 0.01 µF capacitor. |
| 5 | Gnd |  | **Supply Ground**<br>In the PCB layout, the ground pin should be connected to the chassis ground directly. This pin is the internal circuit ground and the silicon substrate ground. |
| 6 | $S_{IND}$ |  | **Stereo Indicator Driver**<br>This driver circuit is intended to light an LED or other indicator when the decoder receives the proper input signals and switches into the stereo mode. The maximum amount of current that the circuit can sink is 10 mA.<br><br>A current limiting resistor is applied externally to control LED brightness versus total power supply current. |
| 7 | $V_{Ref}$ |  | **Regulated Voltage, 1.0 V**<br>An electrolytic capacitor used as a bypass filter is recommended from Pin 7 to ground. The capacitor value should be 10 µF. |
| 8 | $CAP_{Blend}$ |  | **Blend Capacitor**<br>The value of the capacitor on this pin will effect the time constant of the decoder blend function. The recommended value is 10 µF from Pin 8 to ground. The dc level at Pin 8 is internally generated in response to input signal level and signal quality. This pin is a key indicator of the operational state of the IC (see text Functional Description). It is recommended to discharge the blend capacitor externally when changing stations. |
| 9 | $I_{Pilot}$ |  | **Pilot I Detector Output**<br>The Pilot I Detector output requires a 10 µF electrolytic capacitor to ground. The value of this capacitor sets the pilot acquisition time. The dc level at Pin 9 is approximately 1.0 Vdc, unlocked, and 1.1 to 2.4 Vdc in the locked condition. |

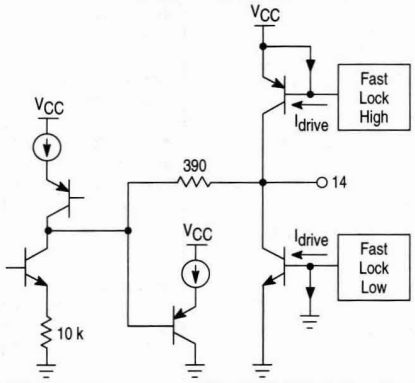
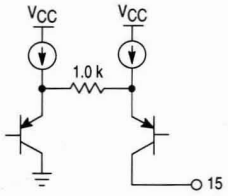
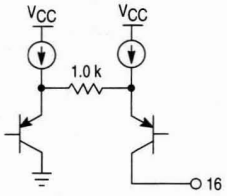
9

## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 10 | $Q_{Pilot}$ |  | **Pilot Q Detector Output**<br>This pin is connected to the Pilot Q detector and requires a 0.47 µF capacitor to ground to filter the error line voltage at the PLL pilot tone detector. If the value of this capacitor is made too large, the decoder may be prevented from coming back into stereo after a signal drop out has been experienced in the field. The force to mono function is also accomplished at this pin by pulling the dc voltage level at the pin below 1.0 V. |
| 11 | $PILOT_{fil}$ |  | **Pilot Signal Input**<br>A capacitor to ground forms a filter for the pilot input signal. The recommended value of the capacitor is 0.22 µF. The dc level at Pin 11 is approximately 1.0 Vdc. |
| 12 | $V_{CC}$ | | **Supply Voltage ($V_{CC}$)**<br>The operating supply voltage range is from 1.8 Vdc to 12 Vdc. |
| 13 | $OSC_{in}$ |  | **Oscillator Input**<br>The oscillator pin requires a ceramic resonator and parallel capacitor connected to ground. The recommended source for the ceramic resonator is Murata, part number CSA 3.60MGF108.<br>A 43 pF NPO capacitor is in parallel with the resonator. The dc level at Pin 13 is approximately 1.1 Vdc. |

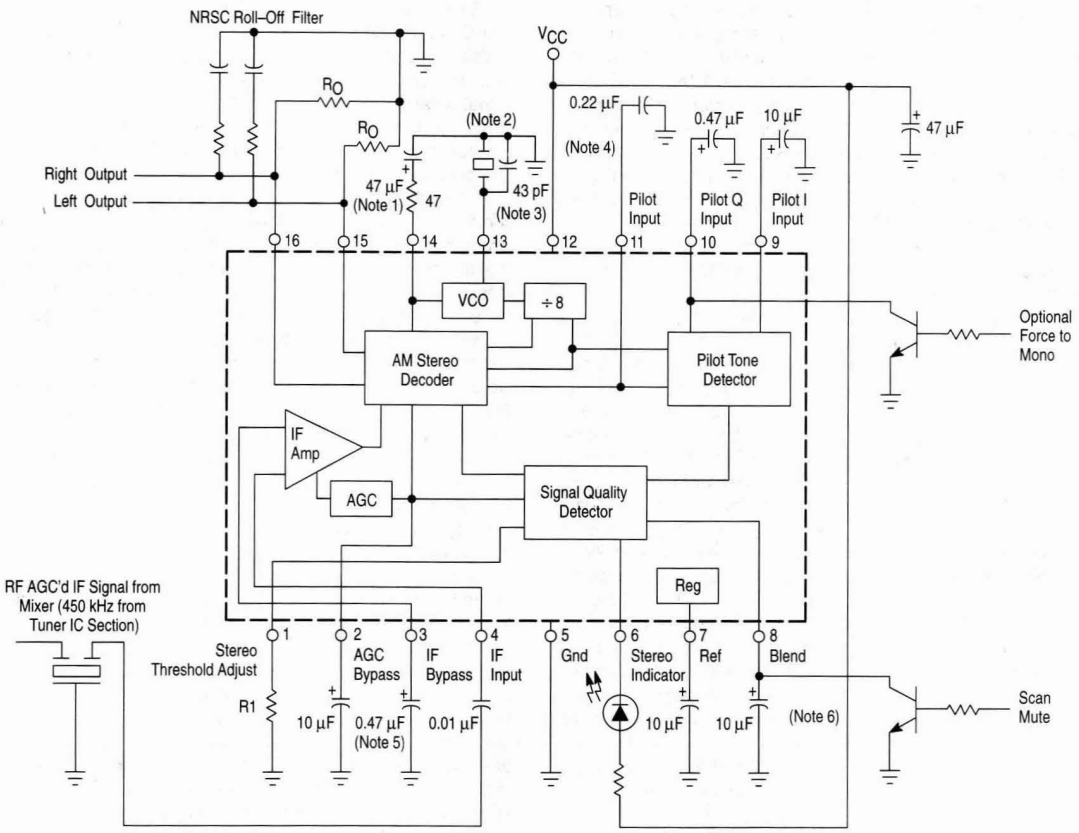
9

## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 14 | $LOOP_{Filter}$ |  | **Loop Filter**<br>A capacitor which forms the loop filter is connected from Pin 14 to ground. The recommended value is 47 µF in series with 47 Ω. This capacitor should be of good construction quality so it will have a very low specification for leakage current in order to prevent stereo distortion. The 47 Ω resistor in series with the capacitor controls the PLL corner frequency response, keeping the response shape critically damped and not peaked up. The dc level at Pin 14 is approximately 0.6 Vdc in the locked condition. |
| 15 | $LEFT_{out}$ |  | **Left Channel Audio Output**<br>This is the left channel audio output pin from which the IC can provide 1.3 $\mu A_{pp}$ drive current for each percent of mono modulation. A resistor to ground sets the level of the audio output.<br>For example, *100%* (mono mod) x 1.3 $\mu A_{pp}$ (IC drive per % mod) = 130 $\mu A_{pp}$ flowing through the load resistor. (For a 2.2 k load, 286 $mV_{pp}$ is then the output signal voltage.) When dealing with stereo signals, multiply the mod level by 2; i.e. *50%* (left only mod) x 2 (stereo factor) x 1.3 $\mu A_{pp}$ (IC drive per % mod) = 130 $\mu A_{pp}$ flowing through the load resistor. |
| 16 | $RIGHT_{out}$ |  | **Right Channel Audio Output**<br>This is the right channel audio output pin. A resistor to ground sets the level of the audio output. See the explanation under the Left Channel Audio Output description above. |

9

**Figure 1. Typical Circuit for E.T.R. Applications**




**NOTES:** 1. The 47 µF capacitor is recommended to be a low leakage type capacitor. Leakage current due to this capacitor causes increase in stereo distortion and decreased separation performance.
2. The recommended source for this part is Murata Products. CSA3.60MGF108. The location of this part should be carefully considered during the layout of the decoder circuit. This part should not be near the audio signal paths, the 25 Hz pilot filter lines, or the $V_{CC}$ high current lines, and the ceramic element ground line should be direct to the chassis ground lead in order to avoid any oscillator inter–modulation.
3. The 43 pF capacitor is recommended to be a NPO type ceramic part. Changing the value of this capacitor alters the lock range of the decoder PLL.
4. The tolerance on the value of the 0.22 µF capacitor should be within ±20% for the full design temperature range of operation. Any reduction in the value of this capacitor due to temperature excursions will reduce the pilot tone circuit sensitivity.
5. The 0.47 µF capacitor is recommended to be a low ESR type capacitor, (less than 1.5 Ω) in order to avoid increased audio output distortions under weak input signal conditions with higher modulation levels.
6. The scan/mute function is located on the Blend pin at Pin 8. To provide this function, Pin 8 should be pulled down below 0.3 V until the decoder and the synthesizer have both locked to a new station.

## FUNCTIONAL DESCRIPTION

### Introduction

The MC13028A is designed as a low voltage, low cost decoder for the C–QUAM AM Stereo technology and is completely compatible with existing monaural AM transmissions. The IC requires relatively few, inexpensive external parts to produce a full featured C–QUAM AM Stereo implementation. The layout is straightforward and should produce excellent stereo performance. This device performs the function of IF amplification, AGC, modulation detection, pilot tone detection, signal quality inspection, and left and right audio output matrix operation. The IC is targeted for use in portable and home AM Stereo radio applications.

A simple overview follows which traces the path of the input signal information to the MC13028A all the way to the audio output pins of the decoder IC.

From the appropriate pin of an AM IC, the IF amplifier circuit of the MC13028A receives its input at Pin 4 as a 450 kHz, typically modulated C–QUAM signal. The input signal level for stereo operation can vary from 47 dBμV to about 90 dBμV. A specific threshold level between these limits can be designed into a receiver by the choice of the resistor value for R1 connected to Pin 1. This IC design incorporates feedback in the IF circuit section which provides excellent dc balance in the IF amplifier. This balanced condition also guarantees excellent monophonic performance from the decoder. An IF feedback filter at Pin 3 is formed by a 0.47 μF low leakage capacitor. It is used to filter out the unwanted audio which is present on the IF amplifier feedback line at higher modulation levels under weak input RF signal conditions. Elimination of the unwanted signal helps to decrease the amount of distortion in the audio output of the stereo decoder under these particular input conditions. An AGC circuit controls the level of IF signal which is subsequently fed to the detector circuits. An AGC bypass capacitor is connected to Pin 2 and forms a single pole low pass filter. The value of this part also sets the time constant for the AGC circuit action.

The amplified C–QUAM IF signal is fed simultaneously to the envelope detector circuit, and to a C–QUAM converter circuit. The envelope detector provides the L+R (mono) signal output which is fed to the stereo matrix. In the converter circuit, the C–QUAM signal is restored to a Quam signal. This is accomplished by dividing the C–QUAM IF signal by the demodulated cos ϕ term. The cos ϕ term is derived from the phase modulated IF signal in an active feedback loop. Cosine ϕ is detected by comparing the envelope detector and the in–phase detector outputs in the high speed comparator/feedback loop. Cosine ϕ is extracted from the I detector output and is actively transferred through feedback to the output of the comparator. The output of the comparator is in turn fed to the control input of the divider, thus closing the feedback loop of the converter circuit. In this process, the cos ϕ term is removed from the divider IF output, thus allowing direct detection of the L–R by the quadrature detector. The audio outputs from both the envelope and the L–R detectors are first filtered to minimize the second harmonic of the IF signal. Then they are fed into a matrix circuit where the Left channel and the Right channel outputs can be extracted at Pins 15 and 16. (The outputs from the I and Q detectors are also filtered similarly.) At this time, a stereo indicator driver circuit, which can sink up to 10 mA, is also enabled. The stereo output will occur if the input IF signal is: larger than the stereo threshold level, not too noisy, and if a proper pilot tone is present. If these three conditions are not met, the blend circuit will begin to force monaural operation at that time.

A blend circuit is included in this design because conditions occur during field use that can cause input signal strength fluctuation, strong unwanted co–channel or power line interference, and/or multi–path or re–radiation. When these aberrant conditions occur, rapid switching between stereo and mono might occur, or the stereo quality might be degraded enough to sound displeasing. Since these conditions could be annoying to the normal listener, the stereo information is blended towards a monaural output. This circuit action creates a condition for listening where these aberrant effects are better tolerated by the consumer.

Intentional mono operation is a feature sometimes required in receiver designs. There are several ways in which to accomplish this feat. First, a resistor from Pin 10 to ground can be switched into the circuit. A value of 1.0 k is adequate as is shown in the schematic in Figure 18. A second method to force the decoder into mono is simply to shunt Pin 10 to ground through an NPN transistor (collector to Pin 10, emitter to ground), where the base lead is held electrically "high" to initiate the action.

A third method to force a mono condition upon the decoder is to shunt Pin 8 of the decoder to ground through an NPN transistor as described above. Effectively, this operation discharges the blend capacitor (10 μF), and the blend function takes over internally forcing the decoder into mono. This third method does not necessarily require extra specific parts for the forced mono function as the first two examples do. The reason for this is that most electronically tuned receiver designs require an audio muting function during turn on/turn off, tuning/scanning, or band switching (FM to AM). When the muting function is designed into an AM Stereo receiver, it also should include a blend capacitor reset (discharge) function which is accomplished in this case by the use of an NPN transistor shunting Pin 8 to ground, (thus making the addition of a forced mono function almost "free"). The purpose of the blend reset during muting is to re–initialize the decoder back into the "fast lock" mode from which stereo operation can be attained much quicker after any of the interruptive activities mentioned earlier, (i.e. turn on, tuning, etc.).

The VCO in this IC is a phase shift oscillator type design that operates with a ceramic resonator at eight times the IF frequency, or 3.60 MHz. With IF input levels below the stereo threshold level, the oscillator is not operational. This feature helps to eliminate audio tweets under low level, noisy input conditions.

The phase locked loop (PLL) in the MC13028A is locked to the L–R signal. This insures good stereo distortion performance at the higher levels of left only or right only modulations. Under normal operating conditions, the PLL remains locked because of the current flow capability of the loop driver circuit. This high gain, high impedance circuit performs optimally when the current flow is balanced. The balanced condition is enhanced by the loop driver filter circuit connected between Pin 14 and ground. The filter circuit consists of a 47 Ω resistor in series with a 47 μF capacitor. The 47 Ω resistor is to set the Fast Lock rate. It is recommended that the capacitor be a very low leakage type electrolytic, or a tantalum composition part because any significant amount of leakage current flowing through the capacitor will unbalance the loop driver circuit and result in less than optimum stereo performance, see Figures 10 and 11.

The pilot tone detector circuit is fed internally from the Q detector output signal. The circuit input employs a low pass filter at Pin 11 that is designed to prevent the pilot tone detector input from being overloaded by higher levels of L–R modulation. The filter is formed by a 0.22 μF capacitor and the input impedance of the first amplifier. A pilot I detector circuit employs a capacitor to ground at Pin 9 to operate in conjunction with an internal resistor to create an RC integration time. The value of the capacitor determines the amount of time required to produce a stereo indication. This amount must include the time it takes to check for the presence of detector falsing due to noise or interference, station retuning by the customer, and pilot dropout in the presence of heavy interference. The pilot Q detector utilizes a filter on its pilot tone PLL error line at Pin 10. This capacitor to ground (usually 0.47 μF) is present to filter any low frequency L–R information that may be present on the error line. If the value of this capacitor is allowed to be too small, L–R modulation ripple on the error line may get large enough to cause stereo dropout. If the capacitor value is made too large, the pilot tone may be prevented from being reacquired if it is somehow lost due to fluctuating field conditions.

A 1.0 V reference level is created internally from the $V_{CC}$ source to the IC. This regulated line is used extensively by circuits throughout the MC13028A design. An electrolytic capacitor from Pin 7 to ground is used as a filter for the reference voltage.

## DISCUSSION OF GRAPHS AND FIGURES

If the general recommendations put forth in this application guide are followed, excellent stereo performance should result.

The curves in Figures 2 through 7 depict the separation and the distortion performance in stereo for 30%, 50%, and 65% single channel modulations respectively. The data for these figures were collected under the conditions of $V_{CC}$ = 8.0 V and $R_O$ = 10 k in both the left and the right channels as applied to the application circuit of Figure 1. A very precise laboratory generator was used to produce the AM Stereo test signal of 450 kHz at 70 dBμV fed to Pin 4. An NRSC post detection filter was not present at the time of these measurements. The audio separation shows an average performance at 30% and 50% modulations of −45 dB in the frequency range of 2.0 kHz to 5.0 kHz. The corresponding audio distortions under these conditions are about 0.28% at 30% modulation, and about 0.41% at 50% modulation.

Figure 6 shows that the typical separation at 65% modulation in the 2.0 kHz to 5.0 kHz region is about −37 dB, and the corresponding audio distortion shown in Figure 7 is about 1.0%. The performance level of these sinusoidal signals is somewhat less than those discussed in the previous paragraph due to the internal operation of the clamping circuits. In the field, the transmitters at AM Stereo radio stations are not usually permitted to modulate single channel levels past 70%. Therefore these conditions do not occur very often during normal broadcast material.

The roll–off at both the low and high frequencies of the 30% single channel driven responses is due to the fact that a post detection bandpass filter of 60 Hz to 10 kHz was used in the measurement of the data, while a post detection filter of 2.0 Hz to 20 kHz was used for the collection of data in the 50% and 65% modulation examples. The tighter bandwidth was used while collecting the performance data at 30% modulation levels in order to assure that the distortion measurement was indicative of the true distortion products measured near the noise floor and thus not encumbered by residual noise and hum levels which would erroneously add to the magnitude of the harmonic distortion data. Note in Figure 8 the traces of noise response for the four different bandwidths of post detection filtering. It can be seen that the noise floors improve steadily with increasing levels of incoming 450 kHz as the value of the lower corner frequency of the filter is increased. Data for the stereo noise floors was collected with the decoder in the forced stereo mode.

**Figure 2. Single Channel Separation at 30% Modulation**

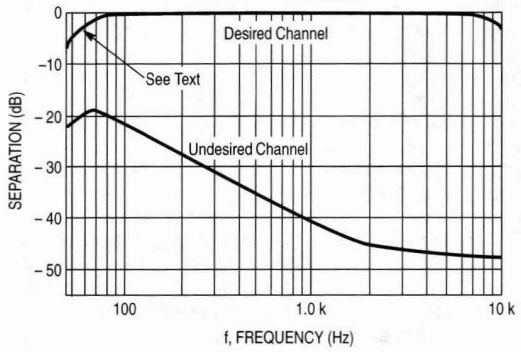



**Figure 3. Single Channel Distortion at 30% Modulation**

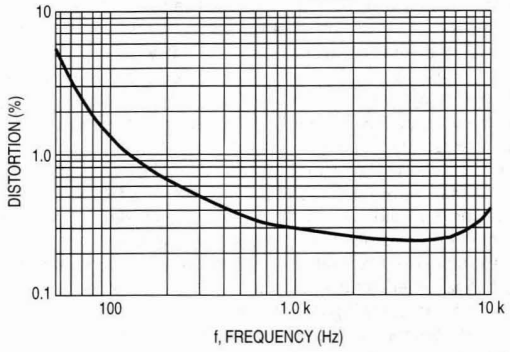



**Figure 4. Single Channel Separation at 50% Modulation**

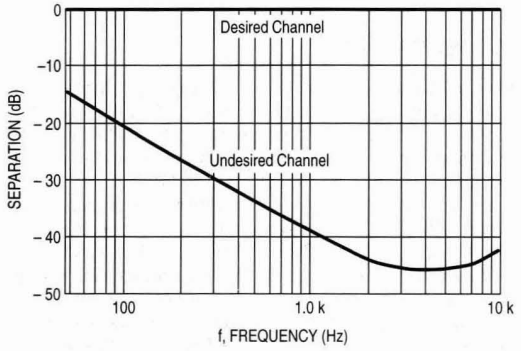



**Figure 5. Single Channel Distortion at 50% Modulation**

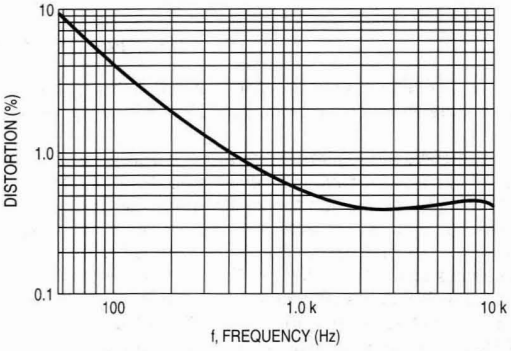



**Figure 6. Single Channel Separation at 65% Modulation**

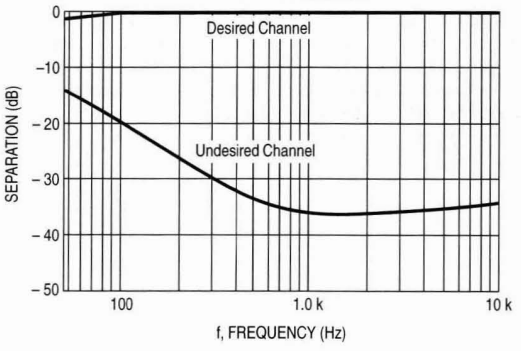



**Figure 7. Single Channel Distortion at 65% Modulation**

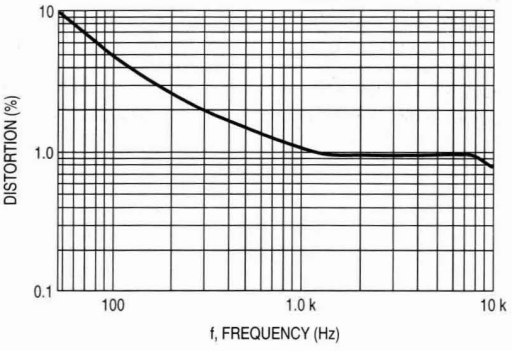


**Figure 8. Stereo Noise and Stereo Composite Distortion when Mono Transmitted**

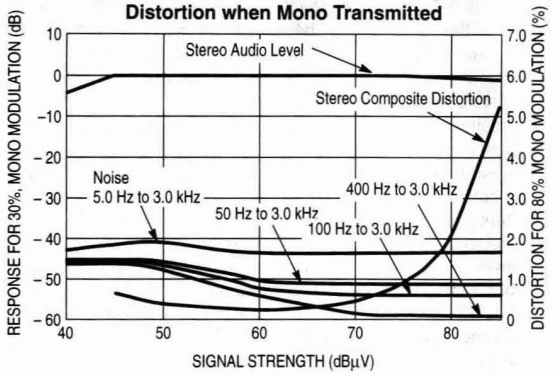

Stereo Audio Level
Stereo Composite Distortion
Noise
5.0 Hz to 3.0 kHz
400 Hz to 3.0 kHz
50 Hz to 3.0 kHz
100 Hz to 3.0 kHz
RESPONSE FOR 30% MONO MODULATION (dB)
DISTORTION FOR 80% MONO MODULATION (%)
SIGNAL STRENGTH (dBμV)

**Figure 9. R1 versus Stereo Threshold Point**

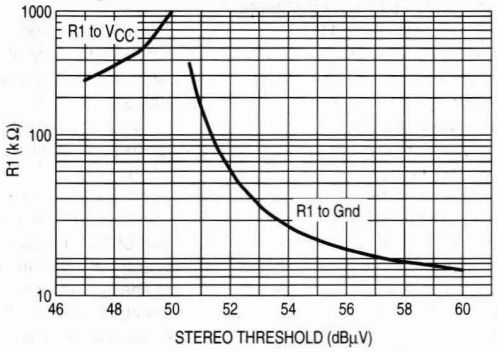



**Figure 10. Decoder Separation versus Filter Capacitor (Pin 14) Leakage Current**

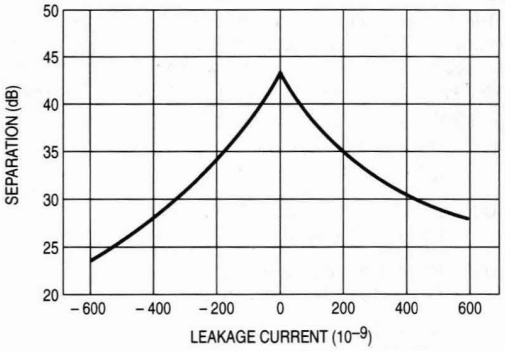



**Figure 11. Decoder Distortion versus Filter Capacitor (Pin 14) Leakage Current**

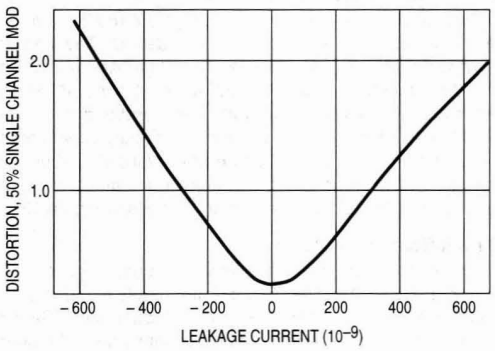



**Figure 12. Low Frequency Corner of PLL Response**

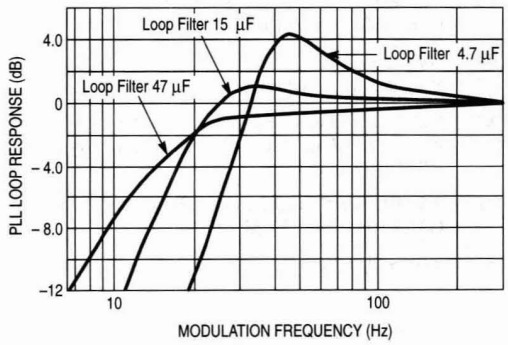



**Figure 13. AGC Voltage versus Input Signal Level**

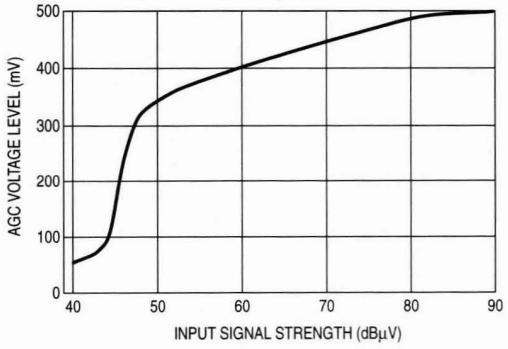



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Figure 9 presents more detailed information with respect to the value of resistor R1 at Pin 1 versus the desired incoming signal level for stereo threshold.

Figures 10 and 11, discussed briefly in the Pin Function Description Section, show the importance of using a quality component at Pin 14 to ground. It can be seen that an electrolytic capacitor leakage current of 600 nA can unbalance the PLL to the point where stereo performance may degrade to only 25 dB of separation with a corresponding 2.0% distortion at 50% modulation levels.

The value of the capacitor connected to Pin 14 (47 μF) is also a factor in the determination of the low frequency corner of the PLL circuit response. Three traces of PLL response appear in Figure 12 where they have been plotted for three different values of loop filter capacitor. The recommended value of 47 μF provides the best response shape in this particular circuit set–up where a Murata Products CSA3.60MGF108 part is used.

Figure 13 presents the response of the AGC voltage versus decoder input signal level. This is a typical response when the IC is used as shown in the application schematic of Figure 1. The trace begins approximately at the point of decoder sensitivity, and rises rapidly until reaching the area of stereo sensitivity, approximately 50 dBμV. Thereafter, the circuit responds in a linear fashion for the next 30 dB of input signal increase.

Figures 14 through 17 inclusively depict the $V_{CC}$ ripple rejection performance for the MC13028A under mono and stereo conditions for nominal and for low values of $V_{CC}$. It should be noted that this data was collected without any $V_{CC}$ filtering. As one might expect, the ripple rejection is better in mono than in stereo. When the decoder operates in stereo, the VCO is functional, thus the decoder becomes more susceptible to audio ripple on the $V_{CC}$ line. Under normal operating conditions, with the recommended value of 47 μF at Pin 12 and 10 μF at Pin 7, a $V_{CC}$ ripple reading will be virtually the same as measuring the noise floor of the IC.

## AM STEREO TUNER / FM STEREO IF

### Description of Application

This application combines a Sanyo LA1832M with the Motorola MC13028A AM Stereo decoder IC. The LA1832 provides an FM IF, FM multiplex detection, AM tuning, and the AM IF functions. The MC13028A provides the AM Stereo detection as well as Left and Right audio outputs. An MC145151 synthesizer provides the frequency control of the local oscillator contained within the LA1832. Frequency selection is by means of a switch array attached to the synthesizer. The application circuit is shown in Figure 18.

### Circuit Board Description

The copper side layout and the component locations are shown in Figure 19. The view is from the plating side of the board, with the components shown in hidden view. Several jumper wires are placed on the component side of the board to complete the circuit. Posts are provided for electrical connections to the circuit. The circuit board has been scaled to fit the page, however, the dimensions provide the true size.

### Circuit Description

The Sanyo data sheet for the LA1832 should be consulted for an understanding of the FM detection and multiplex decoding.

### Special Parts

The following information provides circuit function, part number, and the manufacturer's name for special parts identified by their schematic symbol. Where the part is not limited to a single source, a description sufficient to select a part is given.

| | |
|---|---|
| U1 | IC – AM Stereo Decoder<br>MC13028AD by Motorola |
| U2 | IC – AM/FM IF and Multiplex Tuner<br>LA1832M by Sanyo |
| U3 | IC – Frequency Synthesizer<br>MC145151DW2 by Motorola |
| T1 | AM IF Coil<br>A7NRES–11148N by TOKO |
| F1 | AM IF Ceramic Filter<br>SFG450F by Murata |
| F2 | FM IF Detector Resonator<br>CDA10.7MG46A by Murata |
| F3 | FM Multiplex Decoder Resonator<br>CSB456F15 by Murata |
| F4 | AM Tuner Block<br>BL–70 by Korin Giken |
| X1 | 10.24 MHz Crystal, Fundamental Mode,<br>AT Cut, 18 pF Load Cap, 35 Ω maximum series R.<br>HC–18/U Holder |
| X2 | 3.6 MHz AM Stereo Decoder Resonator<br>CSA3.60MGF108 by Murata |
| S5 | 8 SPST DIP Switch |

**Figure 14. Mono $V_{CC}$ Ripple Rejection**

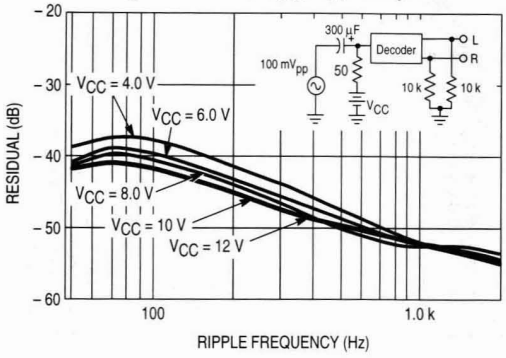


**Figure 15. Mono Low Voltage $V_{CC}$ Ripple Rejection**

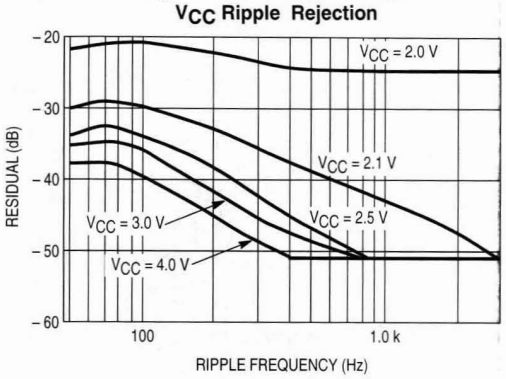


**Figure 16. Stereo $V_{CC}$ Ripple Rejection**

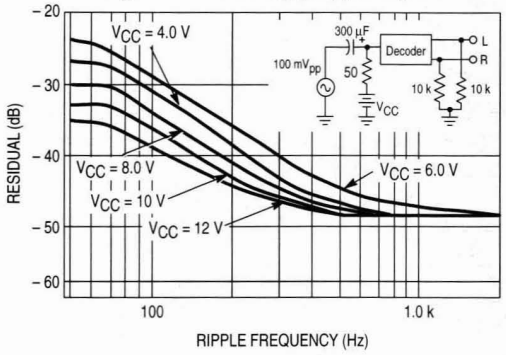


**Figure 17. Stereo Low Voltage $V_{CC}$ Ripple Rejection**

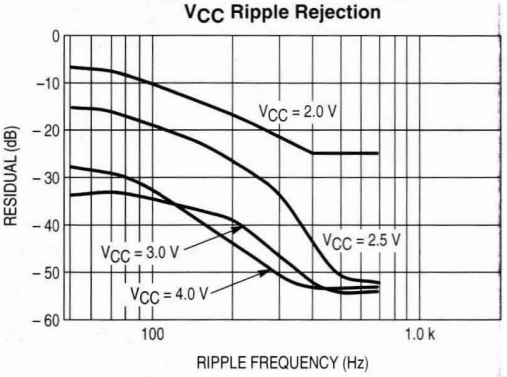


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**Figure 18. MC13028A Decoder IC Application**

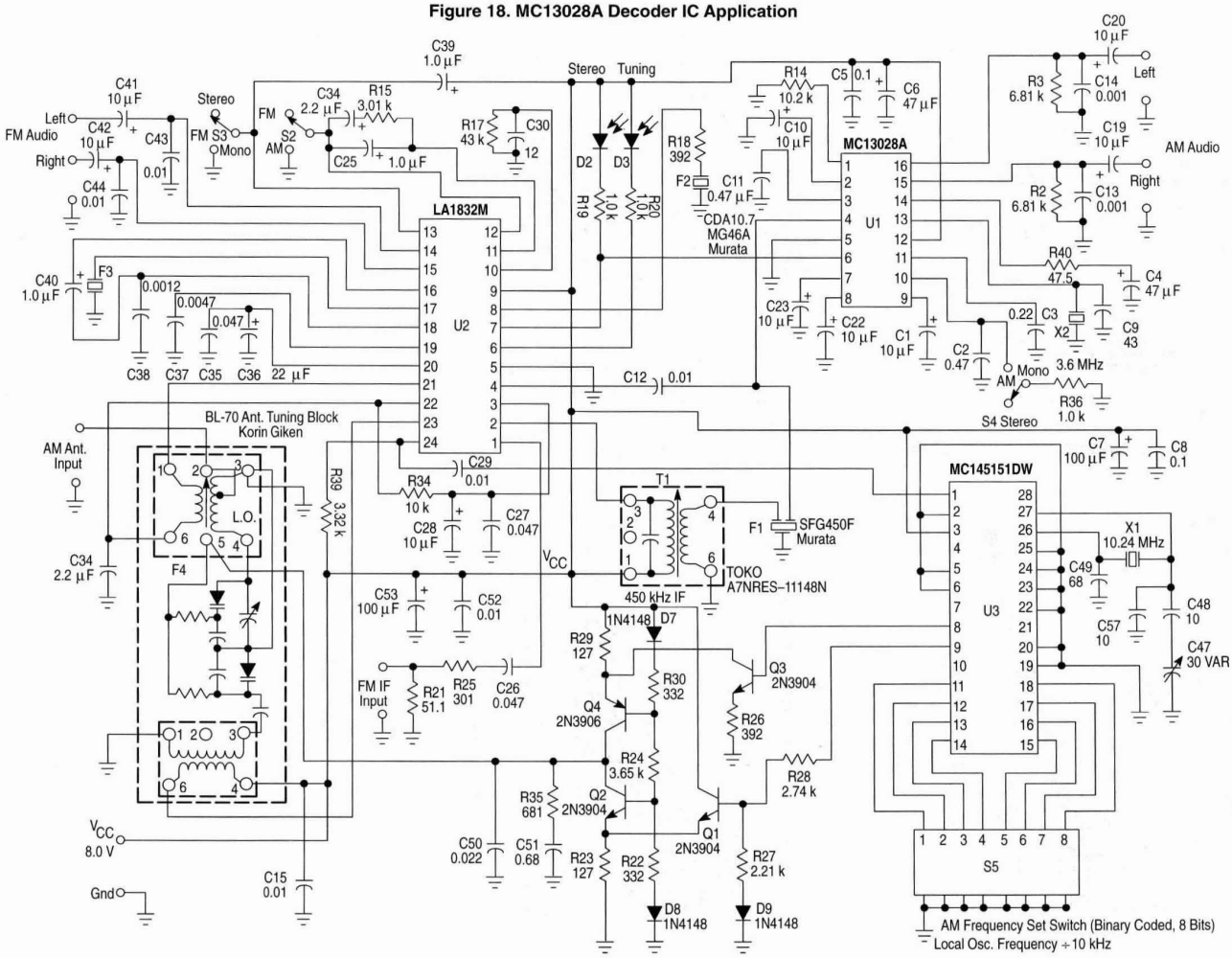
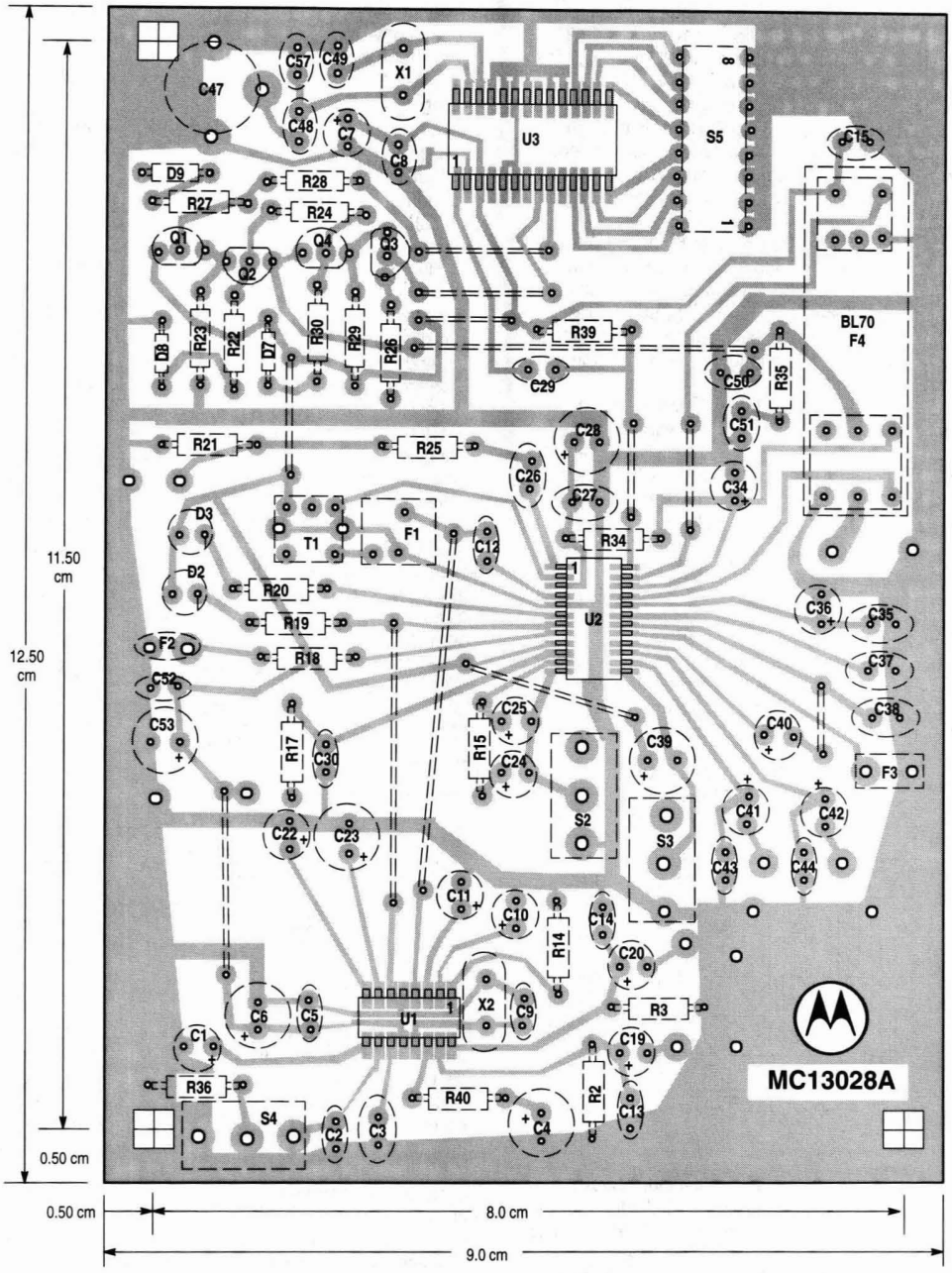


Figure 19. MC13028A Decoder IC Application Circuit Board



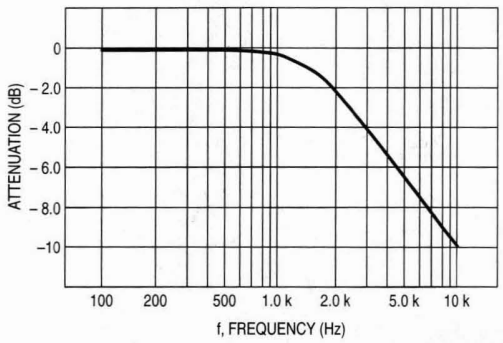
The LA1832 tuner IC (U2) is set for AM operation by switch S2 connecting Pin 12 to ground. An AM Stereo signal source is applied to Pin 2 of the RF coil contained within the BL–70 tuning block. That coil applies the signal to Pin 21 of U2. The L.O. coil is connected from Pin 23 to $V_{CC}$. The secondary is tuned by a varactor which is controlled by a dc voltage output from the synthesizer circuit. The reactance of this oscillator tank is coupled back to Pin 23. It is through this reactance that the frequency of the L.O. is determined. A buffered output from the L.O. emerges at Pin 24. This signal is routed to Pin 1 of the synthesizer (U3), thus completing the frequency control loop.

The mixer output at Pin 2 is applied to the IF coil T1. Coil T1 provides the correct impedance to drive the ceramic bandpass filter F1. The IF signal returns to U2 through Pin 4, and also to the input, Pin 4 of the AM Stereo decoder (U1). The ceramic filter F1 is designed to operate into a load resistance of 2.0 kΩ. This load is provided at Pin 4 of U2.

The stereo outputs exit from Pins 15 and 16 of U1. The design amplitudes of the audio outputs will vary according to the values used for the resistors to ground at Pins 15 and 16 of the decoder, (labeled $R_O$ in the Electrical Characteristics Table and the Test Circuit on page 2 and 3, and in Figure 1, and called R2 and R3 in Figure 18). While the values chosen for $R_O$ are left to the discretion of the designer, the numbers chosen in this data sheet are reflective of those required to set the general industry standard levels of audio outputs in receiver designs.

Pins 15 and 16 are also good locations for the insertion of simple RC filters that are used to comply with the United States NRSC requirement for the shape of the overall receiver audio response. The following curve, Figure 20, shows the response of this U.S. standard.

**Figure 20. NRSC De–Emphasis Curve for the United States**




There are many design factors that affect the shape of the receiver response, and they must all be considered when trying to approximate the NRSC de–emphasis response. The mixer output transformer (IF coil, T1), and ceramic filter probably have the greatest contribution to the frequency response. The ceramic filter can be tailored from its rated response by the choice of transformer impedance and bandwidth. When designing an overall audio response shape, the response of the speakers or earphones should also be considered.

**Component Values.**

The Pin Function Description table gives specific information on the choice of components to be used at each pin of U1. A similar section in the Sanyo LA1832 data sheet should be consulted as to the components to be used with U2.

**Tuning**

The frequency to which the test circuit will tune is set by the eight binary switches contained in the S5 assembly, numbered from 1 to 8. Number 1 connects to Pin 11 of U3 and number 8 connects to Pin 18. The other switches connect to the pins in between and in order. Each individual switch is a SPST type.

To tune to a specific RF frequency, a computation must be made in order to ascertain the divide ratio to input to the synthesizer via the switch array. The divide ratio is simply the eight digit binary equivalent number for the local oscillator frequency divided by 10 kHz. The local oscillator frequency is the desired RF frequency plus 450 kHz, the IF frequency. Any local oscillator value within the AM band can be represented by a binary number. Each binary bit represents a switch setting where a "1" is an open switch and a "0" is a closed switch. The most significant bit represents switch 8 which is connected to Pin 18.

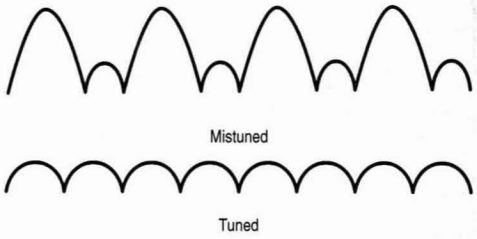
To illustrate, consider the setting for an input frequency of 1070 kHz. (This frequency was used to test the circuit board as described further on.) The local oscillator frequency is 1070 kHz plus 450 kHz which equals 1520 kHz. Dividing by 10 kHz yields the number 152. The binary number for 152 is 10011000. Thus the switches are set to:

| Switch | Position | Number |
|---|---|---|
| 8 | Open | 1 |
| 7 | Closed | 0 |
| 6 | Closed | 0 |
| 5 | Open | 1 |
| 4 | Open | 1 |
| 3 | Closed | 0 |
| 2 | Closed | 0 |
| 1 | Closed | 0 |

**Circuit Adjustments**

The FM circuit requires no adjustment. The AM L.O. must be able to tune from 980 to 2150 kHz to cover the broadcast range. Adjust the core of the L.O. coil if needed in order to be able to cover this range. The AM RF coil and trimmer can be adjusted for best signal after connection to the loop antenna. The coil is adjusted near the low end of the band, and the trimmer is adjusted at the top of the band. The IF coil, T1, is first adjusted for maximum signal out of the filter, F1. This is a "coarse" adjustment. The final "fine tune" adjustment occurs after the following conditions are met. From an AM Stereo generator with the pilot tone off, feed the decoder an input signal of approximately 70 dBμV that is modulated with an 80% L–R audio signal at 3.0 kHz. While monitoring either the left or the right output from the decoder on an oscilloscope, precisely fine tune the IF coil for a minimum residual signal, see the following diagram. If there is no sideband tilt in the system, this adjustment should hold for both channels. Otherwise, the best compromise adjustment for both channels should be used.

**Figure 21. Decoder Signal Output for Mistuned and Tuned Condition with Input Signal of 80% L–R at 3.0 kHz**




### AM Circuit Test

The connections for test are as shown in Figure 22. A 50 Ω resistor is placed on the AM antenna input. The AM Stereo generator is connected to the AM antenna input. Measurements of audio level in mono mode are made with an audio voltmeter connected through a FET probe (pilot signal "off"). Measurements of audio level and distortion in stereo mode (pilot signal "on") are made using a pilot rejection filter ahead of the distortion analyzer or the audio meter. The pilot rejection filter has a rejection ratio that should exceed 20 to 25 dB. Typical data is shown in Figures 23–26. Figures 23 and 24 were read on the left channel in mono mode. Figures 25–26 were in stereo mode.

**Figure 22. MC13028A/LA1832 Application Circuit Board Test Setup**

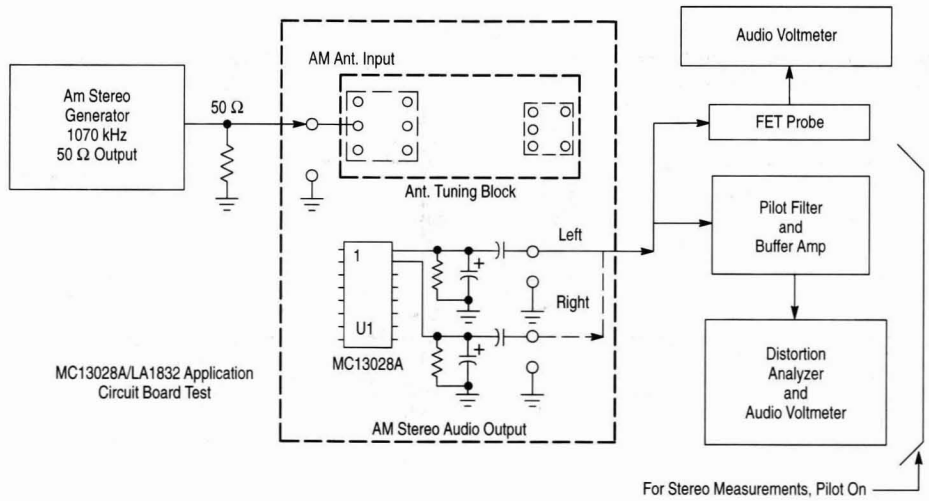


**Figure 23. Left AM Output at 30% Modulation**

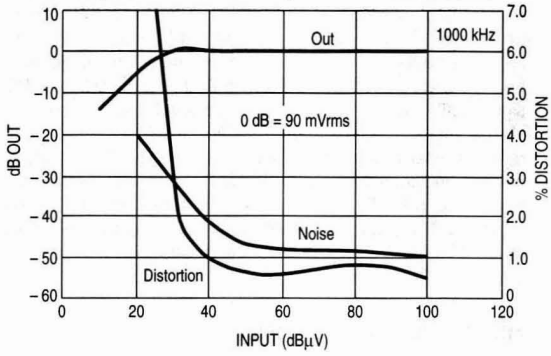



**Figure 24. Left AM Output at 80% Modulation**

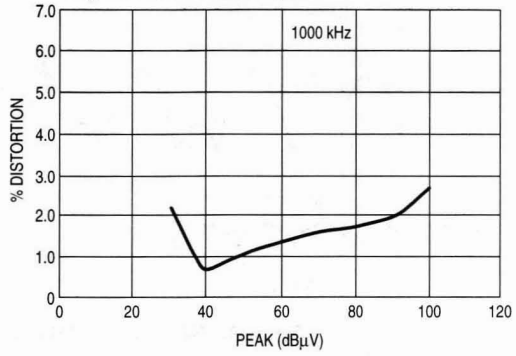



**Figure 25. AM Output Right Channel Only Modulated at 50%**

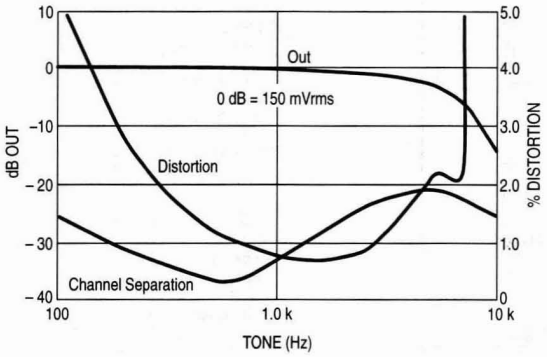
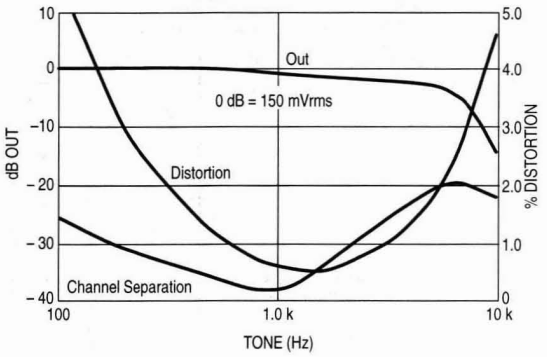



**Figure 26. AM Output Left Channel Only Modulated at 50%**




9

MOTOROLA

# MC13029A

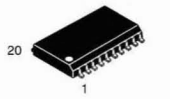
*Advance Information*

## Advanced Medium Voltage IF and C-QUAM® AM Stereo Decoder with FM Amplifier and AM/FM Internal Switch

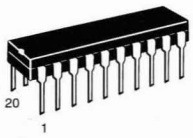
**C–QUAM AM STEREO ADVANCED MEDIUM VOLTAGE IF AND DECODER FOR E.T.R. RADIOS**

The MC13029A is a third generation C–QUAM stereo decoder targeted for use in medium voltage, CD/Cassette, Mini–Component, and Hi–Fi AM/FM Electronically Tuned radio applications. Advanced features include a signal quality detector that analyzes signal strength, signal to noise ratio, and stereo pilot tone before switching to the stereo mode. A "blend function" has been added to improve the transition from both mono to stereo and stereo to mono. The audio output level is adjustable to allow easy interface with a variety of AM/FM tuner chips. The IC further includes an AM/FM switch, an audio mute and internal high pass filtering on AM. The external components have been minimized to keep the total system cost low.

- Operation From 4.0 to 12 V Supply
- IF Amplifier with IF AGC Circuit
- Single Pin–Out, Temperature Compensated VCO
- VCO Shut Down Mode at Weak Signal Condition
- Precision Pilot Tone Detector
- Stereo Blend Function
- Forced Mono Function
- Adjustable Audio Output Level
- AM/FM Switch
- Separate AM De–Emphasis
- Mute Function
- Internal AM High Pass Filters

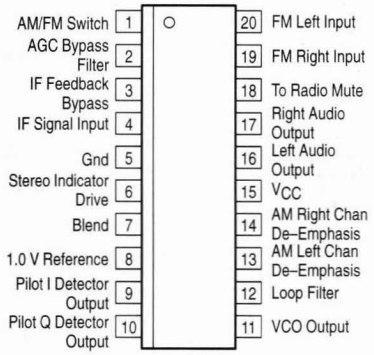



**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20)



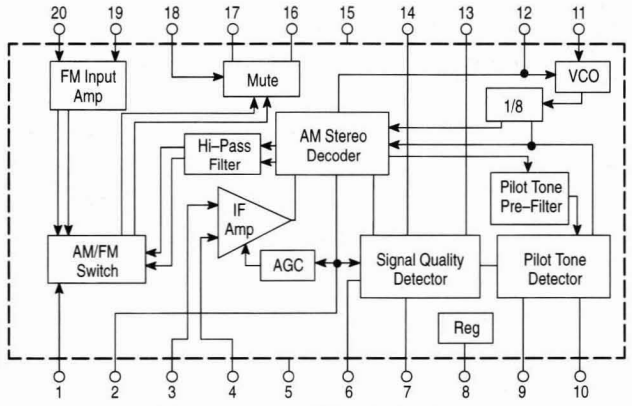

**H SUFFIX**
PLASTIC PACKAGE
CASE 738

**PIN CONNECTIONS**




(Top View)

**Simplified Block Diagram**




This device contains 909 active transistors.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13029ADW | $T_A = -25°$ to $+70°C$ | SO–20 |
| MC13029AH | | DIP–20 |

The purchase of the Motorola C–QUAM® AM Stereo Decoder does not carry with such purchase any license by implication, estoppel or otherwise, under any patent rights of Motorola or others covering any combination of this decoder with other elements including use in a radio receiver. Upon application by an interested party, licenses are available from Motorola on its patents applicable to AM Stereo radio receivers.

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Input Voltage | $V_{CC}$ | 14 | Vdc |
| Operating Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature | $T_A$ | –25 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +150 | °C |
| LED Indicator Current | $I_{LED}$ | 10 | mA |

**NOTE:** ESD data available upon request.

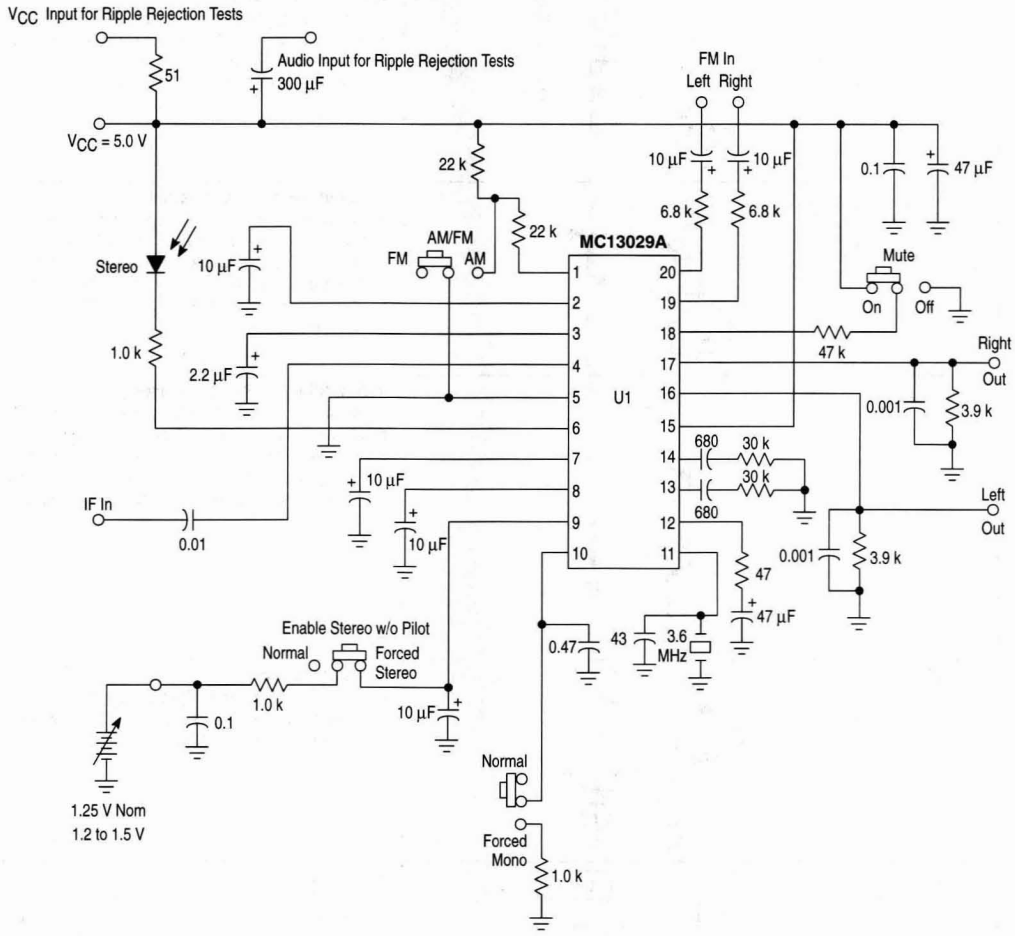
**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $T_A$ = 25°C, Input Signal Level = 74 dBμV, Modulating Signal = 1.0 kHz @ 50% Modulation, Test Circuit of Figure 1, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current Drain<br>$V_{CC}$ = 12 V<br>$V_{CC}$ = 5.0 V | $I_{CC}$ | <br>–<br>9.0 | <br>12<br>11 | <br>–<br>13 | mA |
| Audio Output Level, L+R, Mono Modulation<br>$R_O$ = 3.9 k | $V_{out}$ | 50 | 80 | 110 | mVrms |
| Audio Output Level, L only or R Only, Stereo Modulation<br>$R_O$ = 3.9 k | $V_{out}$ | 110 | 170 | 260 | mVrms |
| Output THD<br>Stereo, L or R Only<br>Mono, L+R | <br>THD1<br>THD2 | <br>–<br>– | <br>0.6<br>0.1 | <br>1.8<br>0.6 | % |
| Channel Separation, L or R Only | R or L | 23 | 35 | – | dB |
| Decoder Input Sensitivity, $V_{out}$ = –10 dB | $V_{in}$ | – | 33 | – | dBμV |
| Force to Mono Mode, at Pin 10 | – | 0.25 | 0.3 | – | Vdc |
| Signal to Noise Ratio<br>Stereo, 50%, L or R Only, 1.0 kHz<br>Mono, 50%, L+R, 1.0 kHz | S/N | <br>40<br>40 | <br>59<br>62 | <br>–<br>– | dB |
| Input Impedance<br>(Reference Specification) | $R_{in}$<br>$C_{in}$ | –<br>– | 10<br>8.0 | –<br>– | kΩ<br>pF |
| Blend Voltage<br>Mono Mode<br>Stereo Mode<br>Out of Lock | BI | <br>0.7<br>1.2<br>– | <br>–<br>1.30<br>0.12 | <br>0.9<br>1.4<br>0.2 | Vdc |
| VCO Lock Range | $OSC_{tun}$ | – | ±2.5 | – | kHz |
| AGC Range | $AGC_{rng}$ | – | 44 | – | dB |
| Channel Balance | C–B | –1.2 | – | 1.2 | dB |
| Pilot Sensitivity | – | – | – | 4.0 | % |

**FM AUDIO SWITCH ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $T_A$ = 25°C, Signal = 1.0 kHz.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| FM Switch Nominal Audio Input<br>$V_{CC}$ = 5.0 V | $V_{in}$ | 200 | – | 500 | $mV_{pp}$ |
| Signal to Noise Ratio (FM Audio Input = 200 mVrms) | S/N | – | 80 | – | dB |
| Channel Separation, L or R Only | R or L | – | >60 | – | dB |
| Output THD<br>FM Audio Input = 200 mVrms<br>FM Audio Input = 500 mVrms | <br>THD1<br>THD2 | <br>–<br>– | <br>0.01<br>– | <br>–<br>2.0 | % |
| AM/FM Switch Input (Pin 1)<br>AM Mode<br>FM Mode | – | <br>–<br>2.6 | <br>–<br>– | <br>0.5<br>– | Vdc |
| Mute Threshold (Pin 18)<br>Mute On<br>Mute Off | – | <br>2.6<br>– | <br>–<br>– | <br>–<br>0.5 | Vdc |

**Figure 1. Test Circuit**

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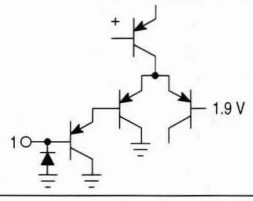
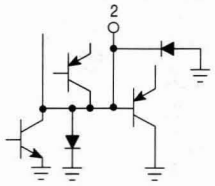
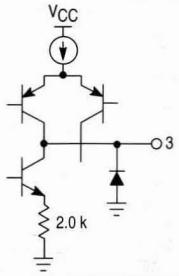
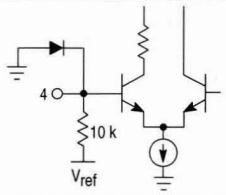
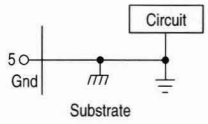
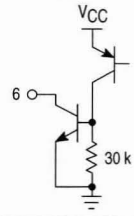
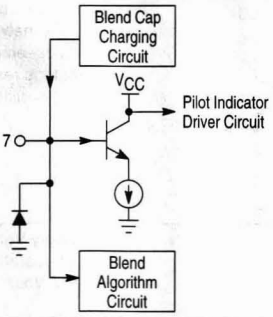
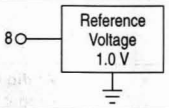
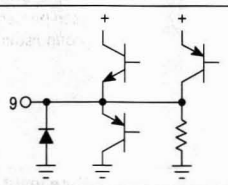
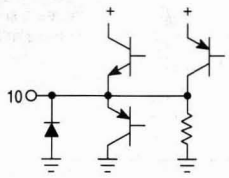
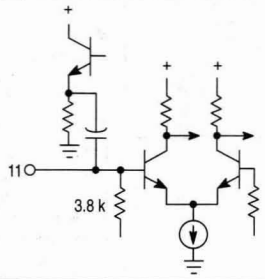
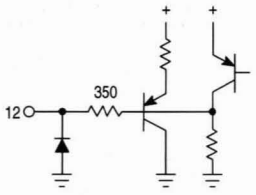
## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 1 | AM/FM |  | **AM/FM Mode Switch**<br>The dc level applied to this pin will determine whether the AM or FM audio is switched to output Pins 16 and 17. A voltage greater than 1.2 V will cause the FM audio to be output. |
| 2 | $AGC_{cap}$ |  | **AGC Filter Bypass Capacitor**<br>An electrolytic capacitor is used as a bypass filter and it sets the time constant for the AGC circuit action. The recommended capacitor value is 10 μF from Pin 2 to ground. The dc level at this pin varies as shown in the curve in Figure 13. AGC Voltage versus Input Level. |
| 3 | $IF_{FBcap}$ |  | **IF Amplifier Feedback Capacitor**<br>A capacitor which is specified to have a low ESR at 450 kHz is normally used at Pin 3. The value recommended for this capacitor is 0.47 μF from Pin 3 to ground. This component forms a low pass filter which has a corner frequency around 30 kHz. |
| 4 | $IF_{in}$ |  | **IF Amplifier Input**<br>Pin 4 is the IF input pin. The typical input impedance at this pin is 10 k. The input should be ac coupled through a 0.01 μF capacitor. |
| 5 | Gnd |  | **Supply Ground**<br>In the PCB layout, the ground pin should be connected to the chassis ground directly. This pin is the internal circuit ground and the silicon substrate ground. |
| 6 | $S_{IND}$ |  | **Stereo Indicator Driver**<br>This driver circuit is intended to light an LED or other indicator when the decoder receives the proper input signals and switches into the stereo mode. The maximum amount of current that the circuit can sink is 10 mA.<br><br>A current limiting resistor is applied externally to control LED brightness versus total power supply current. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 7 | $CAP_{Blend}$ |  | **Blend Capacitor**<br>The value of the capacitor on this pin will effect the time constant of the decoder blend function. The recommended value is 10 µF from Pin 7 to ground. The dc level at Pin 7 is internally generated in response to input signal level and signal quality. This pin is a key indicator of the operational state of the IC (see text Functional Description). It is recommended to discharge the Blend Capacitor externally when changing stations. |
| 8 | $V_{ref}$ |  | **Regulated Voltage, 1.0 V**<br>An electrolytic capacitor used as a bypass filter is recommended from Pin 8 to ground. The capacitor value should be 10 µF. |
| 9 | $I_{Pilot}$ |  | **Pilot I Detector Output**<br>The Pilot I Detector Output requires a 10 µF electrolytic capacitor to ground. The value of this capacitor sets the pilot acquisition time. The dc level at Pin 9 is approximately 1.0 Vdc, unlocked, and 1.1 to 2.4 Vdc in the locked condition. |
| 10 | $Q_{Pilot}$ |  | **Pilot Q Detector Output**<br>This pin is connected to the Pilot Q Detector and requires a 0.47 µF capacitor to ground to filter the error line voltage at the PLL pilot tone detector. If the value of this capacitor is made too large, the decoder may be prevented from coming back into stereo after a signal dropout has been experienced in the field. The force to mono function is also accomplished at this pin by pulling the dc voltage level at the pin below 1.0 V. |
| 11 | $OSC_{in}$ |  | **Oscillator Input**<br>The Oscillator pin requires a ceramic resonator and parallel capacitor connected to ground. The recommended source for the ceramic resonator is Murata, part number CSA 3.60MGF108. A 43 pF NPO capacitor is in parallel with the resonator. The dc level at Pin 11 is approximately 1.1 Vdc. |
| 12 | $LOOP_{Filter}$ |  | **Loop Filter**<br>A capacitor which forms the Loop Filter is connected from Pin 12 to ground. The recommended value is 47 µF in series with 47 Ω. This capacitor should be of good construction quality so it will have a very low specification for leakage current in order to prevent stereo distortion. The 47 Ω resistor in series with the capacitor controls fast lock rate. The dc level at Pin 12 is approximately 0.6 Vdc in the locked condition. |

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**PIN FUNCTION DESCRIPTION (continued)**

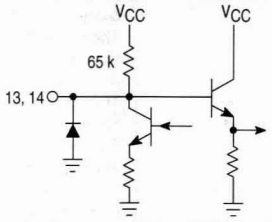
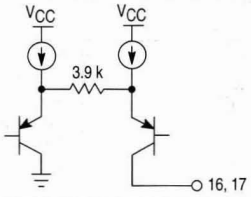
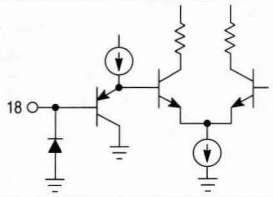
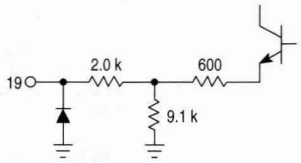
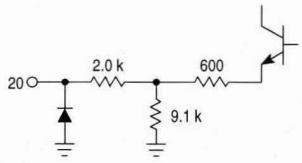
| Pin | Symbol | Internal Equivalent Circuit | Description/External Circuit Requirements |
|---|---|---|---|
| 13<br>14 | DE–L<br>DE–R |  | **AM De–Emphasis, Left Channel/Right Channel**<br>An RC network attached at this pin can be used to add de–emphasis to the AM tone response. The AM tone response is primarily shaped by the IF filter. Additional roll–off may be applied here. |
| 15 | $V_{CC}$ | | **Supply Voltage ($V_{CC}$)**<br>The operating supply voltage range is from 4.0 Vdc to 12 Vdc. |
| 16<br>17 | $LEFT_{out}$<br>$RIGHT_{out}$ |  | **Audio Output**<br>Output is approximately 1.3 $\mu A_{pp}$ drive current for each percent of mono modulation. A resistor to ground sets the voltage level of the audio output. |
| 18 | Mute |  | **Mute Input**<br>A dc voltage exceeding 1.5 V applied to this pin will cause a shutting down of the left and right channel outputs at Pins 16 and 17. |
| 19 | FM–R |  | **FM Audio Right Channel Input**<br>The audio output from the FM detector is input at this pin. The dc level applied at Pin 1, the AM/FM Mode Switch, then determines whether this audio, or that from the AM channel will be output at Pin 17. An external series resistor between this pin and the FM detector is used to set the FM audio levels at the output Pin 17. |
| 20 | FM–L |  | **FM Audio Left Channel Input**<br>The audio output from the FM detector is input at this pin. The dc level applied at Pin 1, the AM/FM Mode Switch, then determines whether this audio or that from the AM channel will be output at Pin 16. An external series resistor, between this pin and the FM detector, is used to set the FM audio levels at the output Pin 16. |

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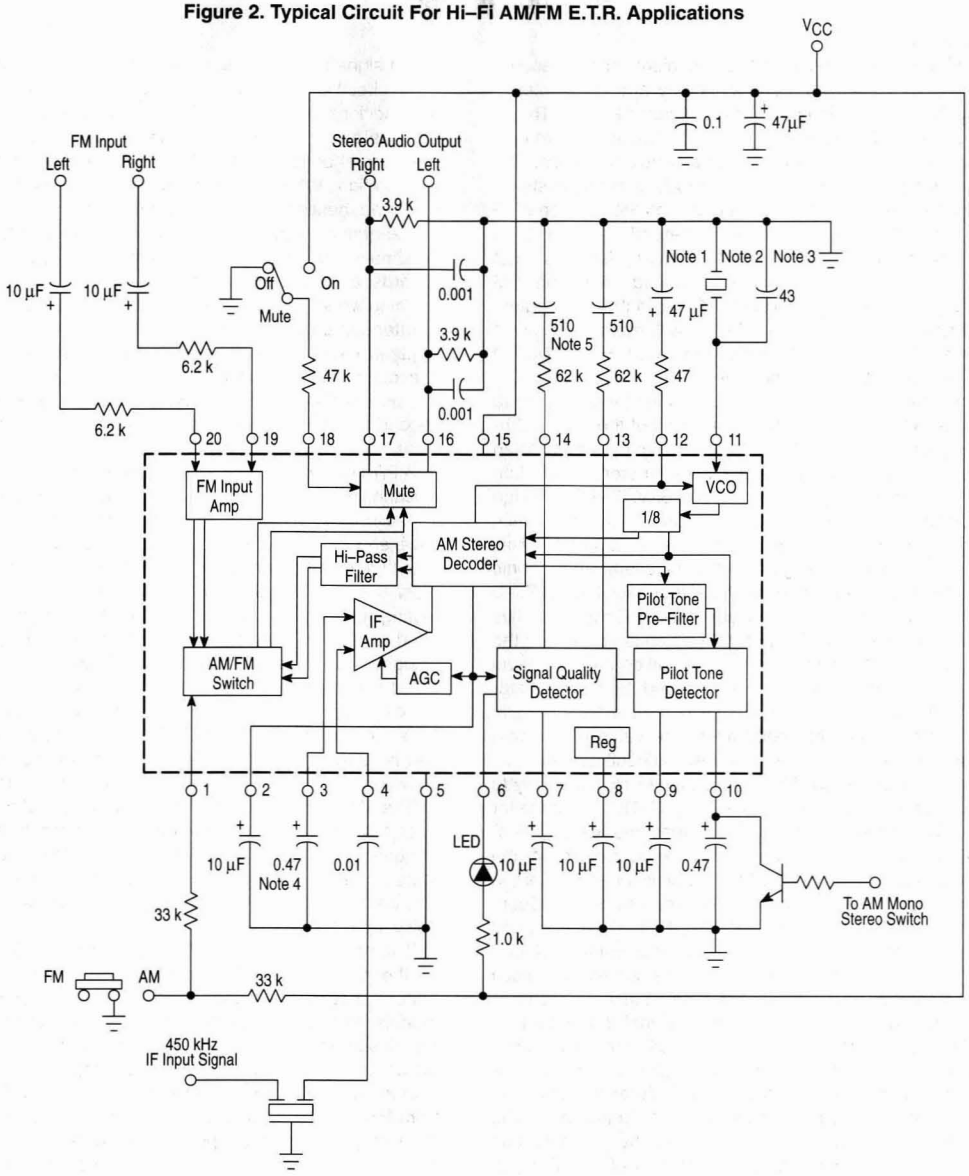
**Figure 2. Typical Circuit For Hi–Fi AM/FM E.T.R. Applications**




**NOTES:** 1. This part is recommended to be a low leakage type capacitor. Leakage current due to this capacitor causes increase in stereo distortion and poor separation performance.

2. The recommended source for this part is Murata Products, CSA3.60MGF108. The location of this part should be carefully considered during the layout of the decoder circuit. This part should not be near the audio signal paths, the 25 Hz pilot filter lines, or the $V_{CC}$ high current lines, and the ceramic element ground line should be direct to the chassis ground lead in order to avoid any oscillator inter–modulation.
3. This capacitor is recommended to be an NPO type ceramic part. Changing the value of this capacitor alters the lock range of the decoder PLL.
4. This part is recommended to be a low ESR type capacitor, (less than 1.5 Ω) in order to avoid increased audio output distortions under weak input signal conditions with higher modulation levels.
5. Component values for this stage of the NRSC filter will vary from receiver manufacturer to manufacturer due to the additive nature of the particular response slopes of the frequency selective parts, (RF and IF coils, and the ceramic IF filter) within a radio design. Since these responses may vary somewhat in each custom design, the filters at Pins 13 and 14 are included to provide any remaining response roll–off that might be necessary to comply with the overall NRSC frequency standard.

# MC13029A

## FUNCTIONAL DESCRIPTION

### Introduction

The MC13029A is designed as a medium voltage decoder for the C–QUAM AM Stereo technology and is completely compatible with existing monaural AM transmissions. The IC requires relatively few, inexpensive external parts to produce a multi–featured C–QUAM AM Stereo implementation. The layout is straightforward and should produce excellent stereo performance results. This device performs the function of IF amplification, AGC, modulation detection, pilot tone detection, signal quality inspection, blend, left and right channel FM input amplification, muting, AM and FM switching function, and amplified left and right audio output levels which are adjustable. The IC is targeted for use in CD/Radio/Cassette, Mini–Component, and Hi–Fi AM/FM E.T.R. AM Stereo radio applications.

From the output of a ceramic IF filter and through a coupling capacitor, the IF amplifier circuit of the MC13029A receives its input at Pin 4 as a 450 kHz, typically modulated C–QUAM signal. The input signal level for stereo operation can vary from 50 dBμV to about 90 dBμV. This IC design incorporates feedback in the IF circuit section which provides excellent dc balance in the IF amplifier. This balanced condition also guarantees excellent monophonic performance from the decoder. An IF feedback filter at Pin 3 is formed by a 0.47 μF, low leakage, low ESR capacitor. It is used to filter out the 450 kHz signal which is present on the IF amplifier feedback line. An AGC circuit controls the level of IF signal which is subsequently fed to the detector circuits. An AGC bypass capacitor is connected to Pin 2 and forms a single pole, low pass filter. The value of this part also sets the time constant for the AGC circuit action.

The amplified C–QUAM IF signal is fed simultaneously to the envelope detector circuit, and to a C–QUAM converter circuit. The envelope detector provides the L+R (mono) signal output which is fed to the stereo matrix. In the converter circuit, the C–QUAM signal is changed into a Quam signal when it is divided by the cos ϕ term. The Quam IF signal is then fed into the I detector, the L–R detector, and the Q detector circuits. The outputs of the Envelope detector and the I detector circuits feed back into a comparator circuit which looks at both signals and uses the differences to create the cos ϕ signal. The Quam IF signal fed to the L–R and the Q detectors is multiplied by a 450 kHz signal that is phased 90° from the one in the I detector circuit. This quadrature relationship is necessary in order to detect the L–R (or stereo) audio information from the Quam signal. The audio outputs from both the Envelope and the L–R detectors are first filtered to minimize the harmonics of the IF signal that are created in the mixing process. (The outputs from the I and Q detectors are also filtered similarly.) Then they are fed into a matrix circuit where the Left channel and the Right channel outputs are extracted and fed into a high pass filter block. Here the audio signals are conditioned so they can be fed to an output amplifier which, if left unmuted, delivers the left and the right output at Pins 16 and 17. At this time, a stereo output will occur if the input IF signal is: a.) larger than the stereo threshold level, b.) not too noisy, and c.) a proper pilot tone is present. At Pin 6, the stereo indicator driver circuit, which can sink up to 10 mA, is also enabled.

After turn on or tune in, if the input signal level threshold for stereo operation is not exceeded, or if the incoming signal is too noisy, the blend circuit, at Pin 7, (even in the presence of a pilot signal) will hold the decoder in the monaural mode. A blend circuit is included in this design because of the effects of conditions which occur during field use that can cause input signal strength fluctuation, strong unwanted co–channel or power line interference, and/or multi–path or re–radiation. When these aberrant conditions occur, rapid switching between stereo and mono might occur, or the stereo quality might be degraded. Since these effects could be annoying to the listener, the stereo information is blended towards a monaural output. This creates a condition for listening where the aberrant effects are more tolerable.

Intentional mono operation is a feature sometimes required in receiver designs. There are several ways in which to accomplish this. First, a 10 k resistor from Pin 10 to ground can be switched into the circuit, as is shown in Figure 18. A second method is to shunt Pin 10 to ground through an NPN transistor as shown in Figure 2.

A third method to force a mono condition on the decoder is to shunt Pin 7 of the decoder to ground through an NPN transistor. This discharges the blend capacitor (10 μF), and the blend function internally forces the decoder into mono. This third method does not necessarily require extra parts as most electronically tuned receiver designs require an audio muting function during turn on/turn off, tuning/scanning, or band switching (FM to AM). When the muting function is designed into an AM Stereo receiver, it also should include a blend capacitor reset (discharge) function. The purpose of the blend reset during muting is to re–initialize the decoder back into the "fast lock" mode from which stereo operation can be attained much quicker after any of the interruptive activities mentioned earlier, (i.e. turn on, tuning, etc.).

The VCO in this IC is a phase shift oscillator type that operates with a ceramic resonator at eight times the IF frequency, or 3.60 MHz. With IF input levels below the stereo threshold level, the oscillator is not operational. This feature helps to eliminate audio tweets under low level, noisy input conditions.

The phase locked loop (PLL) in the MC13029A is locked to the L–R signal. This insures good stereo distortion performance at the higher levels of Left only or Right only modulations. Under normal operating conditions, the PLL remains locked because of the current capability of the loop driver circuit. This high gain, high impedance circuit is filtered by a 47 Ω resistor in series with a 47 μF capacitor from Pin 12 to ground. It is recommended that the capacitor be a very low leakage type electrolytic (less than 200 μA), or a tantalum part. Any significant leakage through the capacitor will unbalance the loop driver circuit and result in less than optimum stereo performance, see Figures 10 and 11.

The pilot tone detector circuit is fed internally by a signal from the Q detector output and is filtered by an internal, 50 Hz low pass pilot pre–filter. This filter is designed to prevent the pilot tone detector input from being overloaded by higher levels of L–R audio modulation. A pilot I detector circuit employs a capacitor to ground at Pin 9 to operate in conjunction with an internal resistor to create an RC integration time. The value of the capacitor affects the amount of time required to produce a stereo indication. The minimal time period must be long enough to include the time it takes for the circuit to check for detector falsing due to noise

or interference, station re–tuning by the customer, and pilot drop–out in the presence of heavy interference. The pilot Q detector incorporates a filter on its pilot tone PLL error line at Pin 10. This capacitor to ground (usually 0.47 μF) is utilized to filter any low frequency information that may be present on the error line. If the value of this capacitor is allowed to be too small, the level of interference near the pilot tone frequency of 25 Hz may become large enough to cause stereo drop–out. If the capacitor value is made too large, the pilot tone may be prevented from being re–acquired if it is somehow lost due to fluctuating field conditions.

A 1.0 V reference level is created within the IC. This regulated line is used extensively by circuits throughout the MC13029A design. An electrolytic capacitor from Pin 8 to ground is used as a filter for the reference voltage.

At Pin 1, the MC13029A provides a function which allows the user to switch between AM and FM audio signals. The actual switching is controlled by dc level with a low for AM and a high for FM audio output.

The level of the audio output at Pins 16 and 17 can be set by the value of a resistor to ground at these pins. The output pins are connected to the collectors of PNP audio output amplifiers. At strong signal, these amplifiers can supply about 1.3 $\mu A_{pp}$ of drive current for each percentage of mono modulation present. In other words, for a 100% LTR signal, 130 $\mu A_{pp}$ will flow through the load. Thus, the value of resistor to ground will determine the peak–to–peak output.

The MC13029A IC provides a true mute function, controlled at Pin 18. A dc level of about 2.6 Vdc is sufficient to ensure muting of the audio outputs at Pins 16 and 17. This feature is useful when tuning in a different radio station, and the designer may also choose to utilize muting when switching between AM and FM.

The FM input audio signals are fed through series external resistors to Pins 19 and 20. Since AM broadcasters normally use heavy audio processing, the value of these resistors is chosen so that the audio output levels of FM are approximately 2.0 dB higher than the audio output levels of AM for the same modulation levels. Under these conditions, there will be only minimal volume differences perceived by the consumer when the MC13029A is switched between AM and FM outputs.

In order to comply with the FCC ruling on the NRSC AM audio response, a connection for de–emphasis circuitry in the MC13029A is provided at Pins 13 and 14 for left and right AM channels respectively. Typically, a series R–C network to ground will provide sufficient additional response shaping to the overall AM response so that the NRSC standard shape can be achieved. The values of these de–emphasis components will vary from design to design. The AM RF and IF coil responses, ceramic filter response and NRSC circuit response all contribute in an additiive manner to the shape of the overall AM audio responses at the IC output pins.

## DISCUSSION OF GRAPHS AND FIGURES

The curves in Figures 3 through 8 depict the separation and the distortion performance in stereo for 30%, 50% and 65% single channel modulations respectively. The data for these figures was collected under the conditions of $V_{CC}$ = 8.0 V and $R_O$ = 3.9 k in both the left and the right channels as recommended in the application circuit of Figure 2. A very precise laboratory generator was used to produce the AM Stereo test signal of 450 kHz at 75 dBμV fed to Pin 4. An NRSC post detection filter was not used. The audio separation shows an average performance at 30% and 50% modulations of –38 dB in the frequency range of 1.0 to 5.0 kHz. The corresponding audio distortions are about 0.3% at 30% modulation and about 0.4% or better at 50% modulation.

Figure 7 shows that the typical separation performance at 65% modulation in the 1.0 to 5.0 kHz region is about –35 dB, and the corresponding audio distortion shown in Figure 8 is about 0.9% or better. The performance level of these sinusoidal signals is somewhat less than those discussed in the previous paragraph due to the internal operation of the clamping circuits. In the field, the transmitters at AM Stereo radio stations are not usually permitted to modulate single channel levels past 70%.

Note the –3.0 dB of roll–off at 80 Hz in the output responses of this decoder. These are the top traces (Desired Channel) in Figures 3, 5 and 7. That roll–off appears by design as a feature to help minimize switching transients present when between AM and FM. This roll–off also provides additional attenuation of pilot tone residuals in the detected audio.

The graphs in Figure 9 show the traces of noise response for four different bandwidths of post detection filtering, measured with respect to 30% mono modulation. It can be seen that the noise floors improve steadily with increasing levels of incoming 450 kHz as the value of the lower corner frequency of the filter is increased. Data for the stereo noise floors was collected with the decoder in the forced stereo mode. The upper trace in Figure 9, labeled Audio Level, shows the response, of the 30% mono signal transmitted, as it appears at the decoder output. The change in response level around 55 dBmV shows the characteristic of the total decoder gain at lower signal inputs.

Figures 10 and 11, discussed briefly in the Function Description Section, show the importance of using a quality component at Pin 12 to ground. It can be seen that an electrolytic capacitor leakage current of 600 nA can unbalance the PLL to the point where stereo performance may degrade to only 25 dB of separation with a corresponding 2.0% distortion at 50% modulation levels.

The value of the capacitor connected to Pin 12 (47 μF) is also a factor in the determination of the low frequency corner of the PLL circuit response. PLL responses appear in Figure 12, plotted for three different values of loop filter capacitor. The recommended value of 47 μF provides the best response shape in this circuit where a Murata Products CSA3.60MGF108 part is used.

Figure 13 presents the response of the AGC voltage versus decoder input signal level in the application schematic of Figure 2. The trace begins approximately at the point of decoder sensitivity, and rises until reaching the area of stereo sensitivity. Thereafter, the circuit responds in a near linear fashion for the next 35 dB of input signal increase.

Figures 14 through 17 depict the $V_{CC}$ ripple rejection performance for the MC13029A under mono and stereo conditions for maximum and for no NRSC filtering. It should be noted that this data was collected without any $V_{CC}$ filtering. As one might expect, the ripple rejection is excellent during mono conditions with approximately 45 dB of 50 Hz to 100 Hz ripple rejection at the high level of NRSC filtering. Under stereo operation, the rejection is the same or better in the 6.0 to 12 V range of operation, as can be seen in Figure 16. When the decoder operates in stereo, the VCO is functional, thus the decoder becomes more susceptible to audio ripple on the $V_{CC}$ line. Under normal operating conditions, with the recommended value of 47 μF at Pin 15 and 10 μF at Pin 8, a $V_{CC}$ ripple reading will be virtually the same as measuring the noise floor of the IC.

**Figure 3. Single Channel Separation at 30% Modulation**

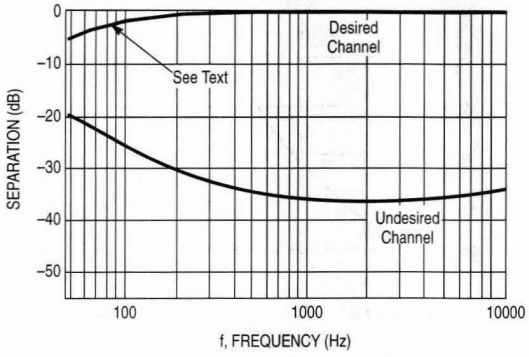



**Figure 4. Single Channel Distortion at 30% Modulation**

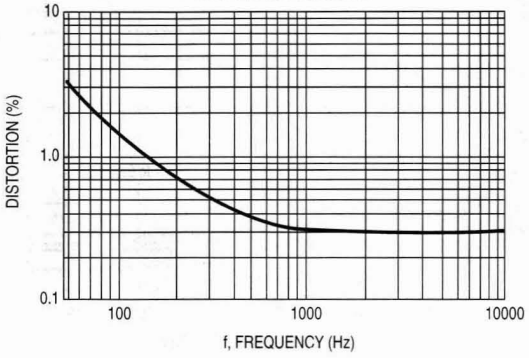



**Figure 5. Signal Channel Separation at 50% Modulation**

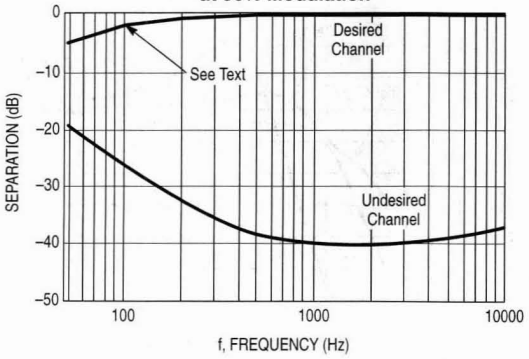



**Figure 6. Single Channel Distortion at 50% Modulation**

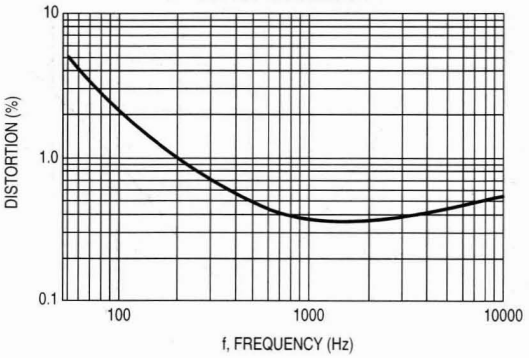



**Figure 7. Single Channel Separation at 65% Modulation**

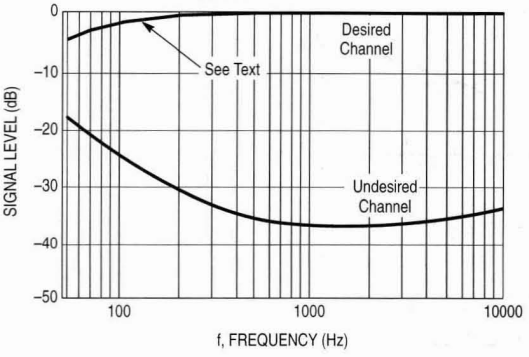



**Figure 8. Single Channel Distortion at 65% Modulation**

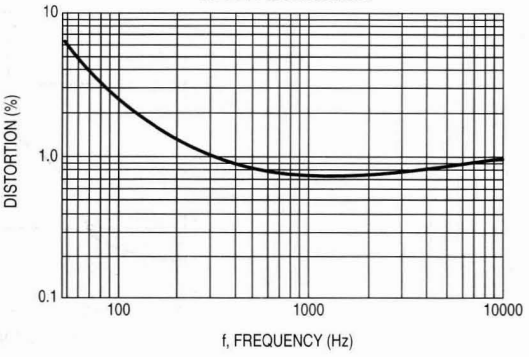



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**Figure 9. Stereo Noise in Various Bandwidths when Mono Transmitted**

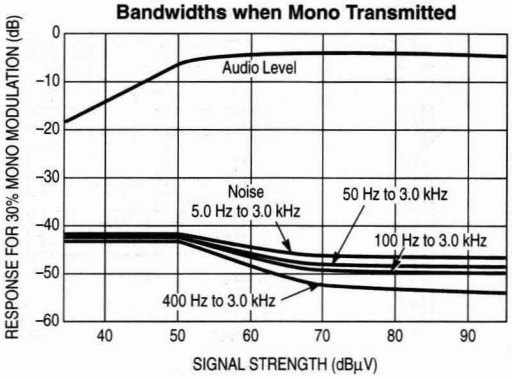



**Figure 10. Decoder Separation versus Filter Capacitor (Pin 12) Leakage Current**

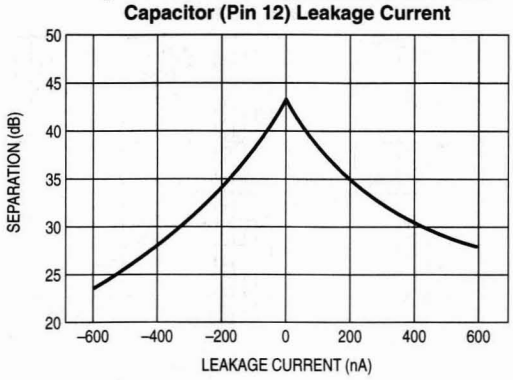



**Figure 11. Decoder Distortion versus Filter Capacitor (Pin 12) Leakage Current**

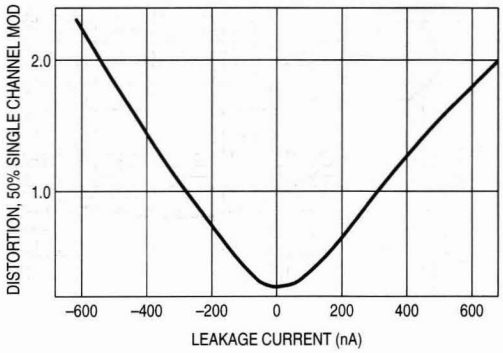



**Figure 12. Low Frequency Corner of PLL Response**

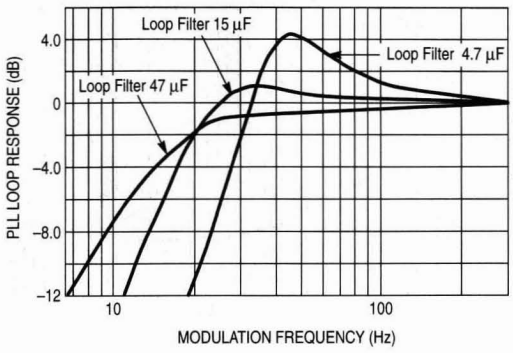
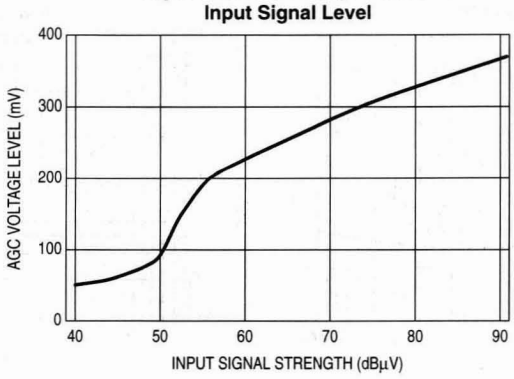



**Figure 13. AGC Voltage versus Input Signal Level**



## AM STEREO TUNER/FM STEREO IF

### Description of Application

The MC13029A AM Stereo Decoder is combined with a Sanyo LA1832 Tuner. The combination results in an AM stereo tuner, along with an FM IF and FM stereo detector. The MC13029A provides the means to switch the left and right channel audio between the AM and FM. A MC145151 synthesizer controls the L.O. contained within the LA1832. The circuit schematic is shown in Figure 18.

### Circuit Board Description

The copper side layout and component locations are shown in Figure 19. The dimensions in the figure give the true size of the circuit board. With the exception of U2 and U3, all components and jumpers are mounted on the side of the board, away from the viewer.

### Special Parts

Table 1 provides the circuit function, part number, and the manufacturer's name for special parts. The parts are identified by their schematic symbol. Where the part is not limited to a single source, a description sufficient to select a part is given.

**Table 1**

| | |
|---|---|
| U1 | IC–AM Stereo Decoder, MC13029A, Motorola |
| U2 | IC–AM/FM IF and Multiplex Decoder, LA1832M, Sanyo |
| U3 | IC–Frequency Synthesizer, MC145151DW2, Motorola |
| T1 | AM IF Coil, A7NRES–11148N, TOKO |
| F1 | AM IF Ceramic Filter, SFG450F, Murata |
| F2 | FM Detector Resonator, CDA10.7MG43, Murata |
| F3 | FM Multiplex Decoder Resonator, CSB456F15, Murata |
| F4 | AM Tuner Block, BL–70, Korin Giken |
| X1 | 10.24 MHz Crystal, Fundamental Mode, AT Cut, 18 pF Load Cap, 35 Ω Max Series R, HC18/U Holder |
| X2 | 3.6 MHz AM Stereo Decoder Resonator, CSA3.60F103, Murata |
| S5 | 8 Section SPST DIP Switch |

**Figure 14. Mono $V_{CC}$ Ripple Rejection with No NRSC Filter**

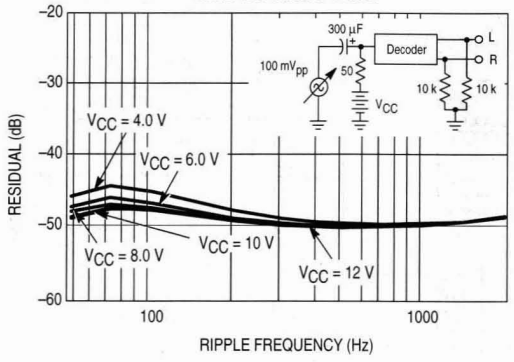



**Figure 15. Mono $V_{CC}$ Ripple Rejection with Maximum NRSC Filter**

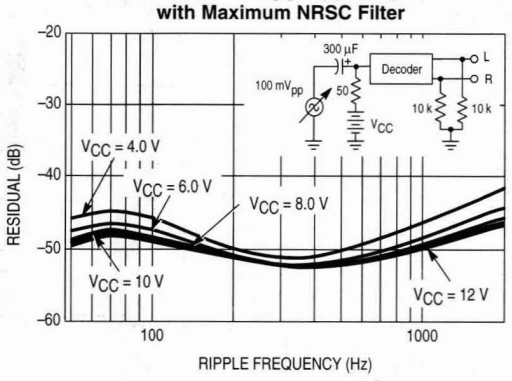



**Figure 16. Stereo $V_{CC}$ Ripple Rejection with No NRSC Filter**

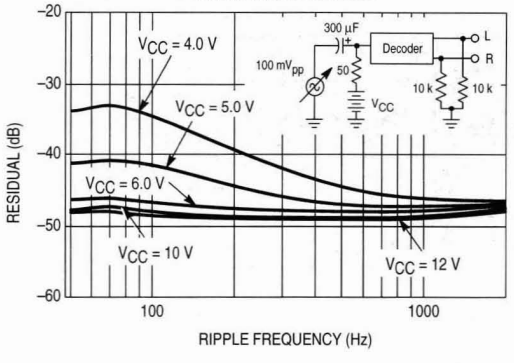



**Figure 17. Stereo $V_{CC}$ Ripple Rejection with Maximum NRSC Filter**

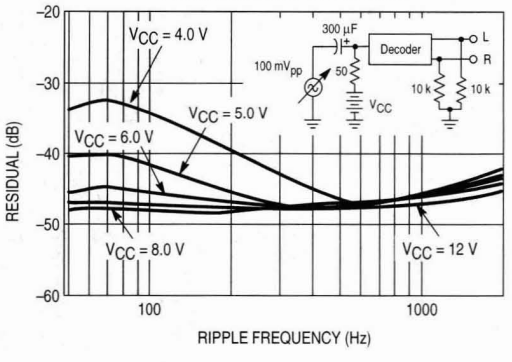


**Figure 18. MC13029A Decoder IC Application**

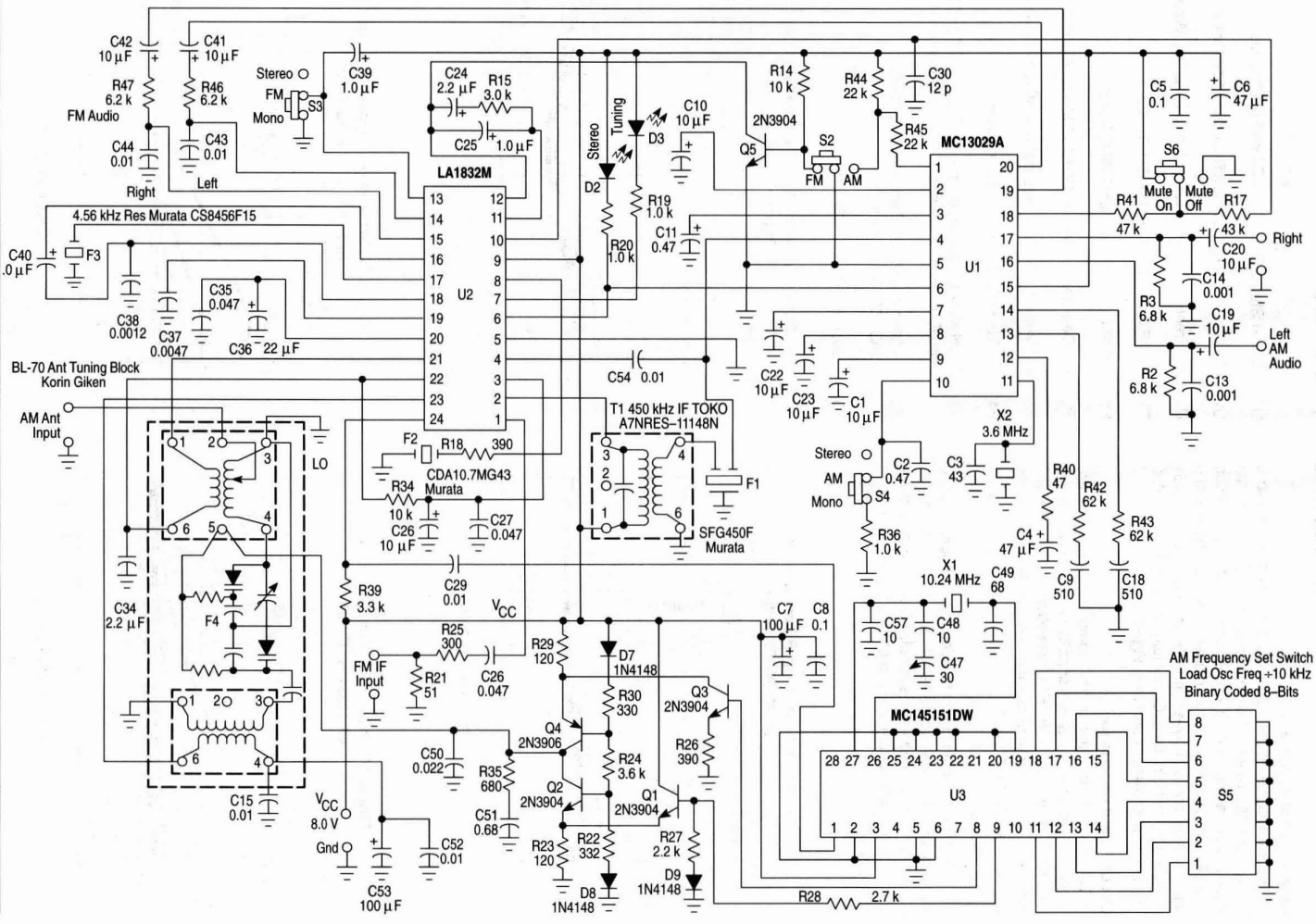
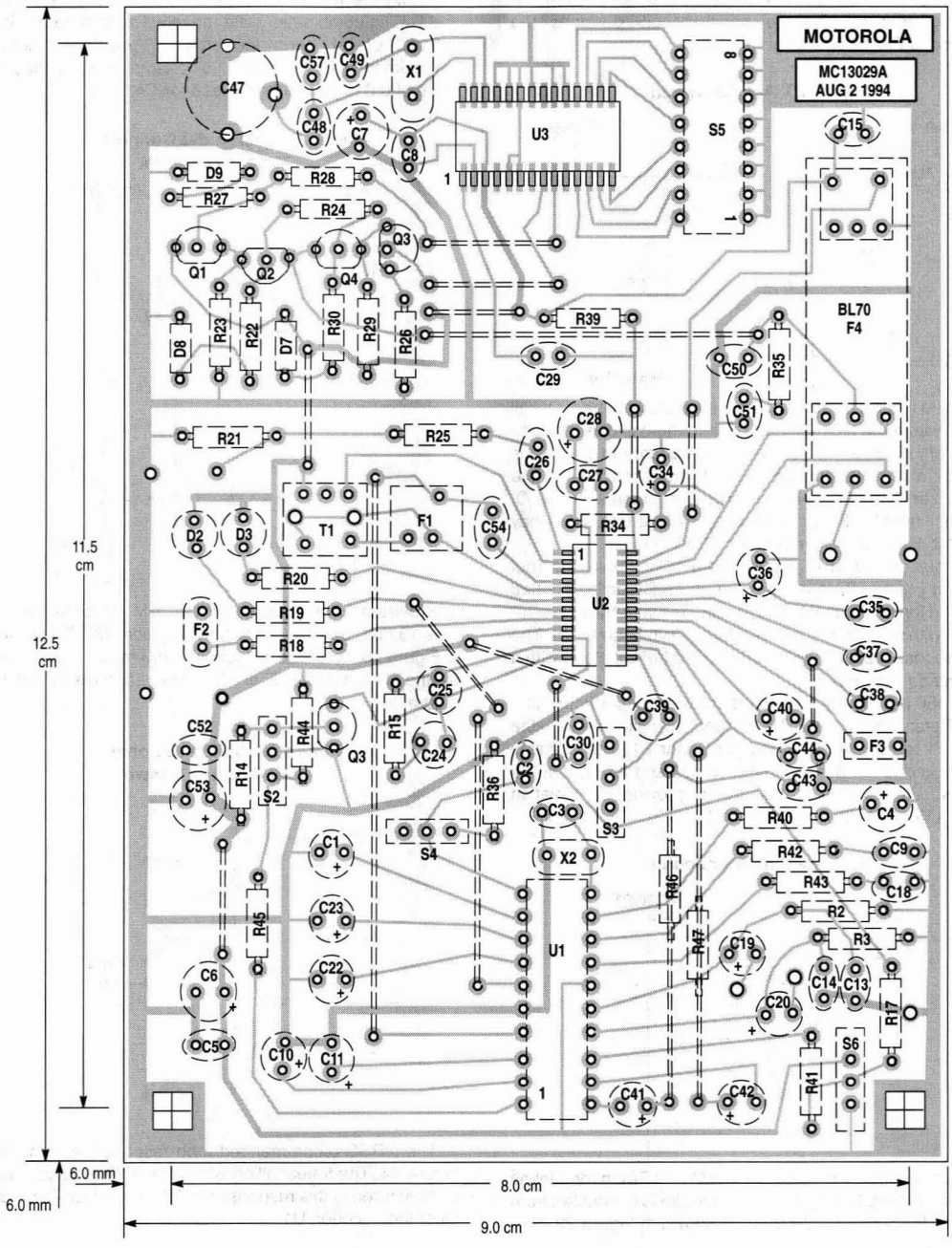


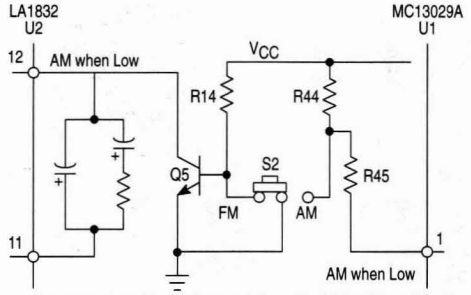
**Figure 19. MC13029A Application Circuit Board**
**Shown 1 1/2 Times Actual Size**



## CIRCUIT DESCRIPTION

To set the circuit to AM mode, Pin 12 of U2 must be pulled to ground, as is Pin 1 of U1. This operation is shown in Figure 20. Pin 12 of U2 must be isolated by a high impedance when in FM mode. To allow switch S2 to accomplish the switching of both ICs, the transistor Q5 performs the switching of Pin 12 of U2.

**Figure 20. AM/FM Switch**

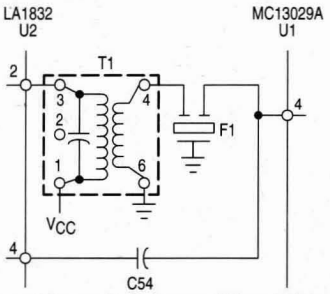



The AM local oscillator is contained in U2 with the L.O. coil located within the tuning block F4, and the coil connected to Pin 23 of U2. See Figure 18. The secondary of the coil is tuned by a varacter contained in F4, and controlled by the synthesizer IC U3. A buffer amplifier outputs the L.O. frequency from U2 Pin 24, This sample of the L.O. frequency is input to Pin 1 of the synthesizer IC U3.

The station signal is applied from a loop antenna (not shown in Figure 18) to the primary of the RF coil contained within the tuning block F4. The primary is tuned by a varactor located within F4, and controlled by the synthesizer U3. The coil secondary applies the signal to Pin 21 of U2 along with a bias voltage from Pin 22 of U2.

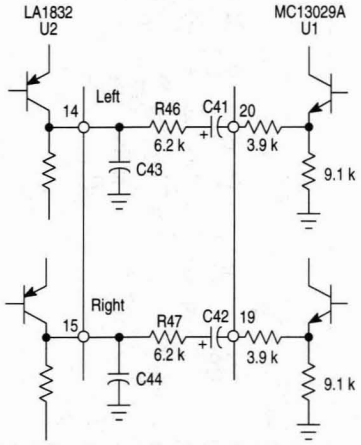
The 450 kHz IF signal from the mixer is output from Pin 2 of U2. Refer to Figure 21. The IF signal is applied through the IF coil T1 to the ceramic band pass filter F1. The signal is then applied to Pin 4 of the tuner IC, U2 and to Pin 4 of the decoder, U1. C54 is necessary to provide dc isolation between Pin 4 of U2 and Pin 4 of U1.

**Figure 21. IF Connection**



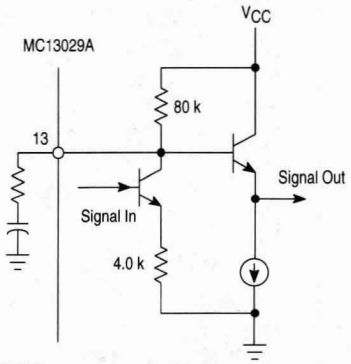

Switching of the audio between AM and FM modes takes place in the decoder IC, U1. The FM audio is conducted from the tuner IC, U2 to the decoder as shown in Figure 22. R46 and R47 provide for the desired balance in audio levels between AM and FM modes. FM de–emphasis is provided by the capacitors C43 and C44. The output impedance of the tuner at Pins 14 and 15 is 5.0 k. The series resistance R46 and R47 in combination with the input resistance at Pins 19 and 20 of U1 bring the effective resistance down to approximately 4.0 k. For a 50 μs de–emphasis, a capacitance value of 0.012 μF would be used for C43 and C44.

**Figure 22. FM Audio Connection Tuner to Decoder**



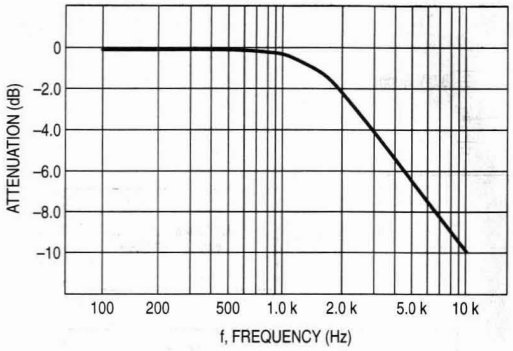

Provision for the application of AM de–emphasis is at Pins 13 (left) and 14 (right) of the decoder U1. This is shown in Figure 23. The tone response in AM mode is primarily set by the IF bandpass filter F1. This response is shown in Figure 28.

**Figure 23. AM De–Emphasis Left Channel Shown**



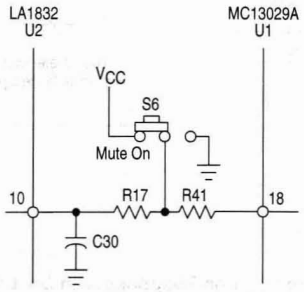

The NRSC recommended tone response is as shown in Figure 24. The tones falling within the IF filter bandpass can be contoured to this response by RC networks at Pins 13 and 14 of the decoder, U1.

**Figure 24. NRSC De–Emphasis Curve for the United States**




For muting, Pin 10 of U2 and Pin 18 of U1 must be pulled high. This is done by switch S6 as is shown in Figure 25.

**Figure 25. Mute Switching**




The AM can be forced to mono by pulling Pin 10 of U1 to ground. This is done by switch S4. Refer to Figure 18. The FM can be forced to mono by pulling Pin 13 of U2 to ground. This is accomplished by switch S3.

### Component Choice

The pin function section of this data sheet gives the information to select the proper components to be used with the MC13029A decoder. A similar section in the LA1832 data sheet provides the information to choose the components for the tuner.

### Tuning

The frequency to which the AM tuner will tune is set by the eight switches contained in the S5 assembly. S5 consists of eight SPST switches. The switches are numbered from 1 to 8. Switch 8 connects to Pin 18 of the synthesizer, U3.

To tune each frequency, the switches are set to a pattern corresponding to that frequency. The pattern is derived from a binary number, equal to the local oscillator frequency divided by 10 kHz.

As an example, consider tuning to 1070 kHz. The local oscillator is 1070 kHz + 450 kHz or 1520 kHz. 1520 kHz/10 kHz is 152. The binary equivalent of 152 is 10011000. The 1 represents an open switch. The 0 represents a closed switch. The left most bit of the binary number is switch 8. Switch 8 is set open. Switch 7 is set closed. This process is continued for all eight bits of the binary number. Table 2 summarizes the switch settings for 1070 kHz.

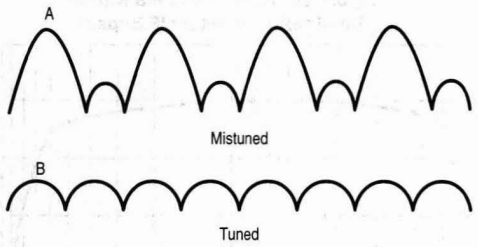
**Table 2**

| Switch | Number | Position |
|---|---|---|
| 8 | 1 | Open |
| 7 | 0 | Closed |
| 6 | 0 | Closed |
| 5 | 1 | Open |
| 4 | 1 | Open |
| 3 | 0 | Closed |
| 2 | 0 | Closed |
| 1 | 0 | Closed |

### Circuit Adjustments

The FM circuit requires no adjustments. The AM L.O. must be able to tune from 990 to 2050 kHz to cover the broadcast range. Adjust the core of the L.O. coil, if needed, to be able to cover this range. The AM RF coil and trimmer can be adjusted for best signal after connection to the loop antenna. The coil is adjusted near the low end of the band, and the trimmer is adjusted at the top of the band. The IF coil T1 is first adjusted for maximum signal out of the filter F1. Final adjustment is shown in Figure 26.

**Figure 26. Decoder Signal Output for Mistuned and Tuned Condition with Input Signal of 80% L–R and 3.0 kHz**




Apply an AM Stereo signal modulated with a 3.0 kHz tone at 80% L–R. Set the pilot tone off. Observe either the left or right channel audio. When T1 is properly adjusted, the waveform should appear as waveform B shown in Figure 26. Adjust T1 as required. If the waveform can only be adjusted to appear as waveform A, then adjust for least amplitude and equal amplitudes on both the left and right channels.

### AM Circuit Test

The connections for test are as shown in Figure 27. A 50 Ω resistor is placed on the AM antenna input. The AM Stereo generator is connected to the AM antenna input. Measurements of audio level are made with an audio voltmeter with a high input impedance (1.0 MΩ). Measurements of distortion in stereo mode are made using a 400 Hz high pass filter ahead of the distortion analyzer. Typical data is shown in Figures 28 through 34.

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**Figure 27. Test Circuit**

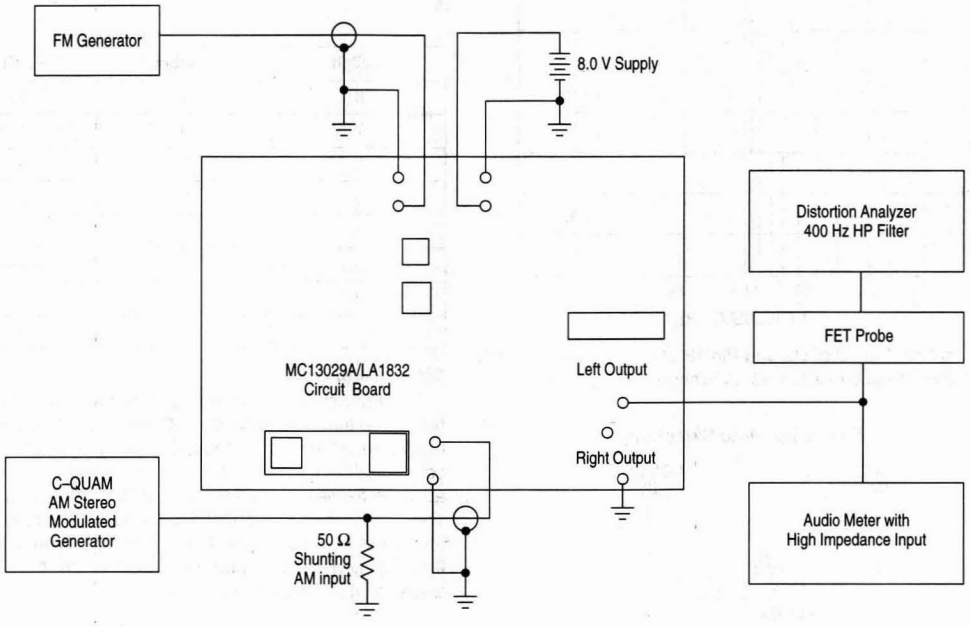



**Figure 28. Tone Response without De–Emphasis Set by IF Bypass**

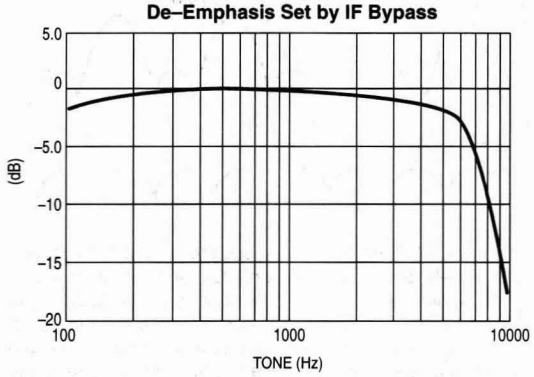



**Figure 29. Tone Response with De–Emphasis**

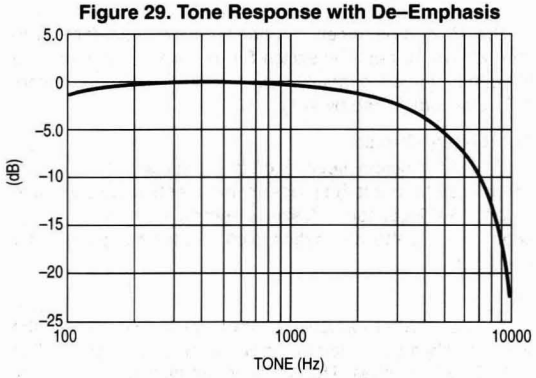


**Figure 30. Single Channel Separation at 50% Modulation**

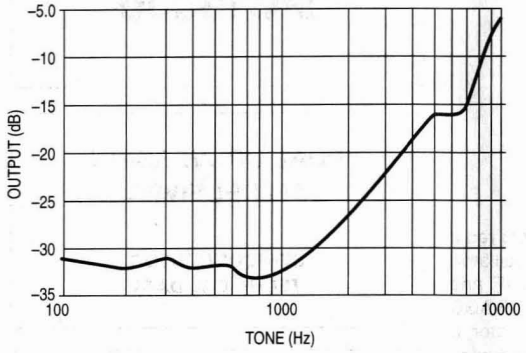



**Figure 31. Single Channel Distortion at 50% Modulation**

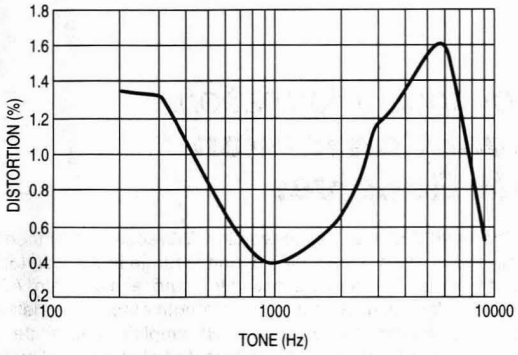



**Figure 32. Mono Characteristics at 30% Modulation**

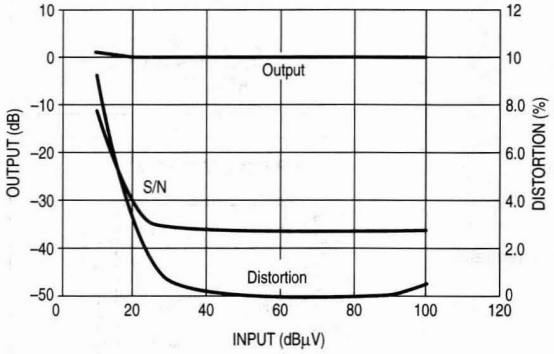



**Figure 33. Mono Characteristics at 80% Modulation**

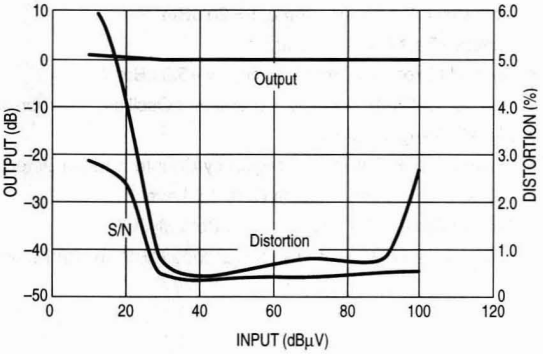
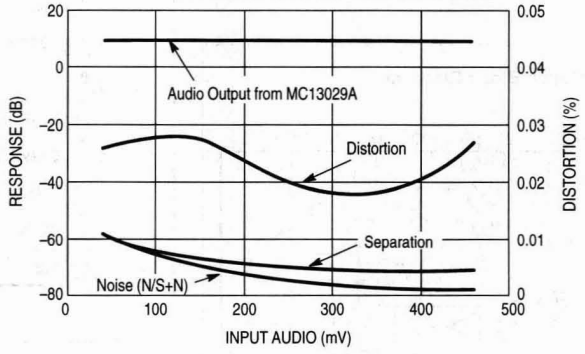



**Figure 34. AM/FM Audio Switch Performance of Left FM Channel with 1.0 kHz Audio Tone**

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MOTOROLA

# MC13030

*Advance Information*

## Dual Conversion AM Receiver

**DUAL CONVERSION AM RECEIVER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13030 is a dual conversion AM receiver designed for car radio applications. It includes a high dynamic range first mixer, local oscillator, second mixer and second oscillator, and a high gain AGC'd IF and detector. Also included is a signal strength output, two delayed RF AGC outputs for a cascode FET/bipolar RF amplifier and diode attenuator, a buffered IF output stage and a first local oscillator output buffer for driving a synthesizer. Frequency range of the first mixer and oscillator is 100 kHz to 50 MHz.

Applications include single band and multi–band car radio receivers, and shortwave receivers.

- Operation from 7.5 to 9.0 Vdc
- First Mixer, 3rd Order Intercept = 20 dBm
- Buffered First Oscillator Output
- Second Mixer, 3rd Order Intercept = +5.0 dBm
- No Internal Beats Between 1st and 2nd Oscillator Harmonics
- Signal Strength Output
- Limited 2nd IF Output for Frequency Counter Station Detector
- Adjustable IF Output Station Detector Level
- Adjustable RF AGC Threshold for Both Mixer Inputs
- Two Delayed AGC Outputs for Cascode RF Stage and Diode Attenuator

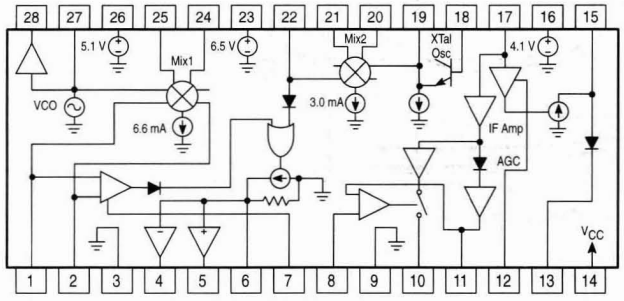
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751F

**PIN CONNECTIONS**

| | | | |
|---|---|---|---|
| 1 | Mix1 In | VCO Out | 28 |
| 2 | Mix1 In | VCO | 27 |
| 3 | RF Gnd | VCO Ref | 26 |
| 4 | FET RF AGC | Mix1 Out | 25 |
| 5 | RF AGC2 | Mix1 Out | 24 |
| 6 | RF AGC Adj | $V_{ref}$ | 23 |
| 7 | Mix1 RF AGC Adj | Mix2 In | 22 |
| 8 | SD Level | Mix2 Out | 21 |
| 9 | IF Gnd | Mix2 Out | 20 |
| 10 | SD IF Out | Xtal Osc E | 19 |
| 11 | S Level Out | Xtal Osc B | 18 |
| 12 | IF AGC In | IF In | 17 |
| 13 | AF Out | Det $V_{ref}$ | 16 |
| 14 | $V_{CC}$ | Det In | 15 |

(Top View)

**Representative Block Diagram**




This device contains 335 active transistors.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13030DW | $T_A$ = –40° to +85°C | SOIC–28 |

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply | $V_{CC}$ | 10 | V |
| Operating Temperature | $T_A$ | –40 to +85 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Junction Temperature | $T_J$ | 150 | °C |

**NOTE:** ESD data available upon request.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 8.0 V, unless otherwise noted.)

| Characteristic | Condition/Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Power Supply Voltage | – | $V_{CC}$ | 7.5 | 8.0 | 9.0 | V |
| Power Supply Current | $V_{CC}$ = 8.0 V | $I_{CC}$ | 26 | 32 | 44 | mA |
| Detector Output Level | $V_{in}$ = 1.0 mV, 30% Mod. | V13 | 160 | 200 | 240 | mVrms |
| Audio S/N Ratio | $V_{in}$ = 1.0 mV, 30% Mod. | S/N | 48 | 52 | – | dB |
| Audio THD | $V_{in}$ = 1.0 mV, 30% Mod.<br>$V_{in}$ = 1.0 mV, 80% Mod.<br>$V_{in}$ = 2.0 mV, 80% Mod. | THD | –<br>–<br>– | 0.3<br>0.3<br>0.4 | 1.0<br>1.0<br>1.5 | % |
| Signal Strength Output | $V_{in}$ = 0 to 2.0 V | V11 | 0 | – | 5.2 | V |
| VCO Buffer Output | – | V28 | 178 | 224 | 282 | mV |
| SD Output Level | $V_{in}$ = 1.0 mV, V11 > V8 | V10 | 2.3 | 2.7 | 3.3 | Vpp |
| **MIXER1** | | | | | | |
| Input Resistance | 1 or 2 to Gnd | – | – | 10 | – | kΩ |
| Third Order Intercept Point | 1 or 2 | IP3 | – | 127 | – | dBμV |
| Conversion Transconductance | 1 or 2 to 24 + 25 | $g_c$ | – | 2.2 | – | mS |
| Total Collector Current | 24 + 25 | $I_C$ | – | 4.6 | – | mA |
| Input IF Rejection | 1 or 2 | – | – | 45 | – | dB |
| **MIXER2** | | | | | | |
| Input Resistance | 22 | – | – | 2.4 | – | kΩ |
| Third Order Intercept Point | 22 | IP3 | – | 112 | – | dBμV |
| Conversion Transconductance | 22 to 20 + 21 | $g_c$ | – | 4.6 | – | mS |
| Total Collector Current | 20 + 21 | $I_C$ | – | 3.0 | – | mA |
| **VCO** | | | | | | |
| Minimum Oscillator Coil Parallel Impedance | 27 to 26 | $R_P$ | – | 3.0 | – | kΩ |
| Buffer Output Level | 28 | $V_O$ | – | 224 | – | mVrms |
| Stray Capacitance | 27 | $C_S$ | – | 7.0 | – | pF |
| **IF AMPLIFIER** | | | | | | |
| Input Resistance | 17 | $R_{in}$ | – | 2.0 | – | kΩ |
| Transconductance | 17 to 15 | $g_m$ | – | 28 | – | mS |
| Maximum Input Level | 17 | $V_{in}$ | – | 125 | – | mVrms |
| Minimum Detector Coil Parallel Impedance | 17 to 15 | $R_L$ | – | 15 | – | kΩ |
| RF Output Level | 15, $V_{in}$ = 1.0 mV | – | – | 2.0 | – | Vpp |
| Audio Output Impedance | 13 | $R_{out}$ | – | 120 | – | Ω |
| Audio Output Level | 13 @ 30% Mod. | $V_{out}$ | – | 200 | – | mVrms |

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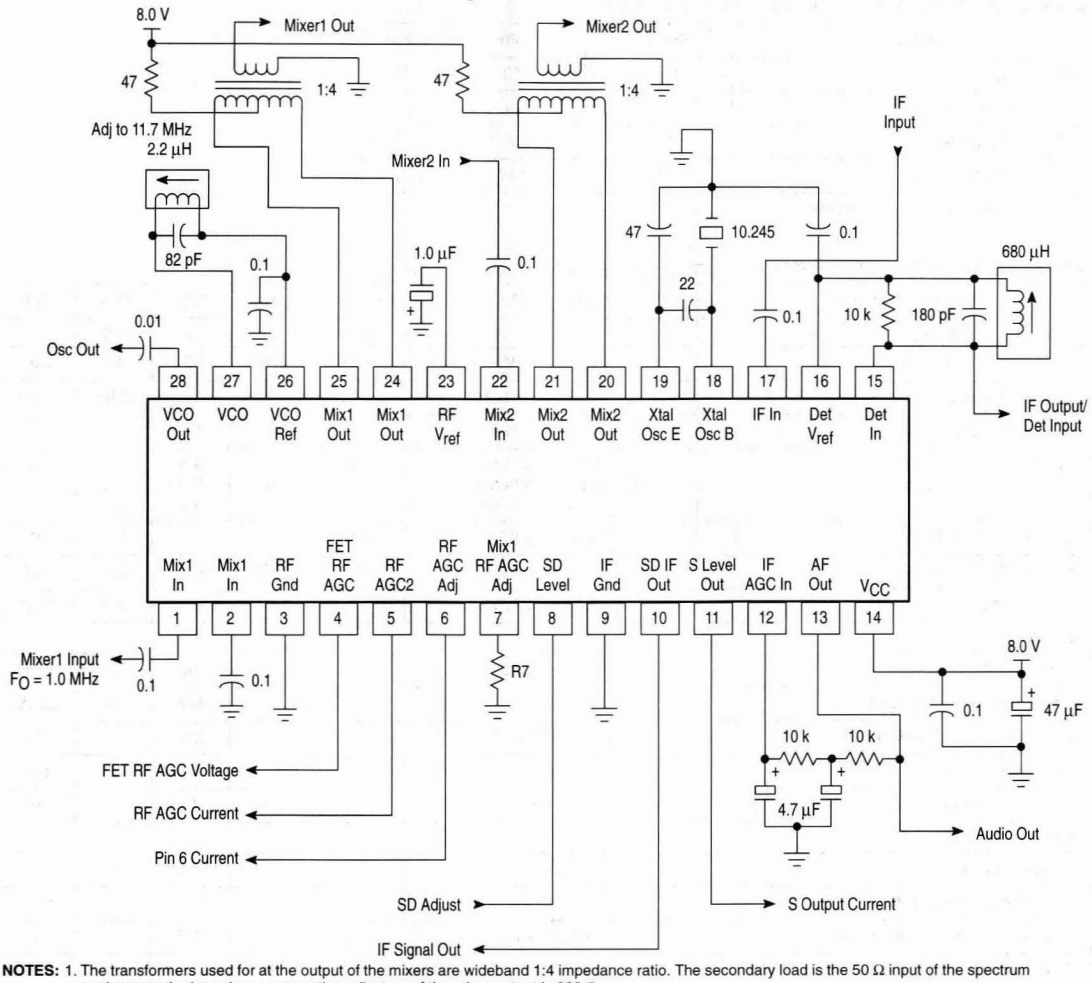
**Figure 1. Test Circuit**




**NOTES:** 1. The transformers used for at the output of the mixers are wideband 1:4 impedance ratio. The secondary load is the 50 Ω input of the spectrum analyzer, so the impedance across the collectors of the mixer output is 200 Ω.
2. Since the VCO frequency is not critical for this measurement, a fixed tuned oscillator tuned to 11.7 MHz is used. This gives an input frequency of 1.0 MHz.
3. The detector coil is loaded with a 10 k resistor to reduce the tuned circuit Q and to present a 10 kΩ load to the IF output for determination of IF transconductance.
4. The RF AGC current, S output current and Pin 6 current are measured by connecting a current measuring meter to these pins, so they are effectively shorted to ground.
5. SD adjust is adjusted by connecting a power supply or potentiometer and voltmeter to Pin 8.

## FUNCTIONAL DESCRIPTION

The MC13030 contains all the necessary active circuits for an AM car radio or shortwave receiver.

The first mixer is a multiplier with emitter resistors in the lower, signal input transistors to give a high dynamic range. It is internally connected to the first oscillator (VCO). The input pins are 1 and 2. The input can be to either Pins 1 or 2, or balanced. These pins are internally biased, so a dc path between them is allowable but not necessary. The mixer outputs are open collectors on Pins 25 and 26. They are normally connected to a tuned transformer.

The first oscillator on Pin 27 is a negative resistance type with automatic level control. The level is low so the signal does not modulate the tuning diode capacitance and cause distortion. Pin 26 is the reference voltage for the oscillator coil. This reference is also the supply for the mixer circuits. The upper bases of the mixer are 0.7 V below this reference.

The second mixer is similar to the first, but it is single–ended input on Pin 22. Its outputs are open collectors on Pins 20 and 21 which are connected to a tuned transformer. The dynamic range of this mixer is less than the first. It is also connected internally to an oscillator which is normally crystal controlled. The oscillator is a standard Colpitts type with the emitter on Pin 19 and the base on Pin 18.

The IF amplifier input is Pin 17. The AGC operates on the input stage to obtain maximum dynamic range and minimum distortion. The IF output, Pin 15, is a current source.

Therefore, its gain is determined by the load impedance connected between Pins 15 and 16. Pin 16 is a voltage reference for the output. The output is internally connected to the AM detector, and Pin 13 is the detector output. This detector also provides the AGC signal for the IF amplifier. An RC filter from Pin 13 to 12 removes the audio, leaving a dc level proportional to the carrier level for AGC.

Pin 11 provides a current proportional to signal strength. It is a current source so a resistor must be connected from Pin 11 to ground to select the desired dc voltage range. The current is proportional to the signal level at Pin 17, the IF amplifier input.

A high–gain limiting amplifier is used to derive the station detect (SD) signal output on Pin 10; this output is present only if it is turned on by the voltage on Pin 8. If the voltage on Pin 8 is less than the voltage on Pin 11, the output on Pin 10 is "on". The station detector IF output on Pin 10 is used with synthesizers which have a frequency counting signal detector.

The RF AGC outputs on Pins 4 and 5 are controlled by the signal levels at Mixer1 or Mixer2. Bypass capacitors are required on Pins 6 and 4 to remove audio signals from the AGC outputs. Pin 4 is designed to control the NPN transistor in series with the RF amplifier FET. The voltage on Pin 4 is 5.1 V with no input signal and decreases with increasing input signal. Pin 5 is designed to control an additional AGC circuit at the antenna input. The voltage on Pin 5 is at 0 V with no input signal and increases with increasing input signals. The voltage on Pin 5 does not increase until the voltage on Pin 4 has decreased to about 1.3 V. In most cases, Pin 5 is used to drive a diode shunt. Maximum output current is about 850 µA.

The RF AGC sensitivity is about 40 mVrms input to Mixer1 or about 2.0 mVrms input to Mixer2 at 1.0 MHz. The AGC sensitivity for both mixers can be decreased by adding a resistor from Pin 6 to ground. There is also an additional amplifier between Mixer1 and its AGC rectifier. The gain of this amplifier and AGC sensitivity for Mixer1 can be increased by adding a resistor from Pin 7 to ground. Therefore, the desired AGC sensitivity for both mixers can be achieved by changing the resistors on Pins 6 and 7.

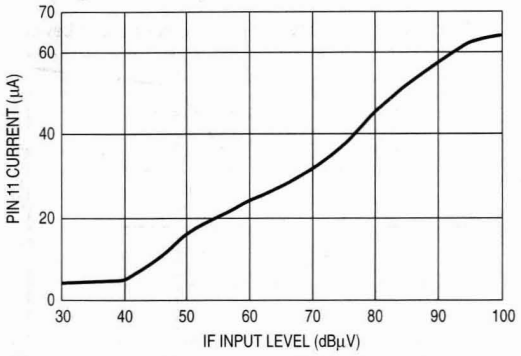
**Figure 2. Pin Connections and DC Voltages**

| | | | | | |
|---|---|---|---|---|---|
| 3.3 V | 1 | Mix1 In | VCO Out | 28 | 5.1 V |
| 3.3 V | 2 | Mix1 In | VCO | 27 | 5.1 V |
| 0 V | 3 | RF Gnd | VCO Ref | 26 | 5.1 V |
| 5.1 to 0 V | 4 | FET RF AGC | Mix1 Out | 25 | 7.8 V |
| 0 to 850 µA<br>0 to 2.8 V | 5 | RF AGC2 | Mix1 Out | 24 | 7.8 V |
| 200 mV | 6 | RF AGC Adj | $V_{ref}$ | 23 | 6.5 V |
| 43 mV | 7 | Mix1 RF AGC Adj | Mix2 In | 22 | 3.7 V |
| 0 to 4.8 V | 8 | SD Level | Mix2 Out | 21 | 7.9 V |
| 0 V | 9 | IF Gnd | Mix2 Out | 20 | 7.9 V |
| 6.5 V | 10 | SD IF Out | Xtal Osc E | 19 | 4.4 V |
| 0 to 4.8 V | 11 | S Level Out | Xtal Osc B | 18 | 5.0 V |
| 3.6 to 4.5 V | 12 | IF AGC In | IF In | 17 | 4.8 V |
| 3.6 to 4.5 V | 13 | AF Out | Det $V_{ref}$ | 16 | 4.1 V |
| 8.0 V | 14 | $V_{CC}$ | Det In | 15 | 4.1 V |

**S Out versus IF Input:**

The S output current at Pin 11 is provided by two collectors, one a PNP source and the other a sink to ground. The desired S output voltage can be selected using the curve of Figure 3 and calculating the value of the required resistor.

**Figure 3. S Output Current versus IF Input Level**




**RF FET AGC versus Mixer1 and Mixer2 Input Level:**

Figures 4 and 5 are generated with no external resistance on Pins 4 or 6, so they represent the minimum RF AGC sensitivity of Mixer1 and Mixer2.

**Figure 4. RF AGC Voltage versus Mixer1 Input**

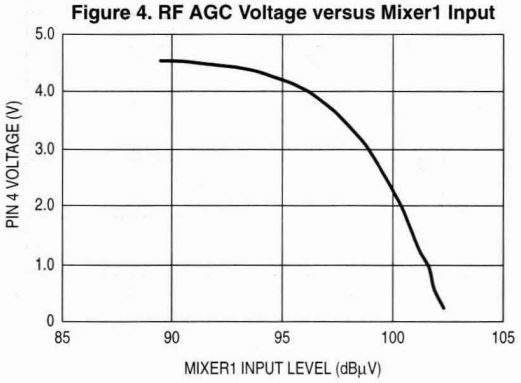
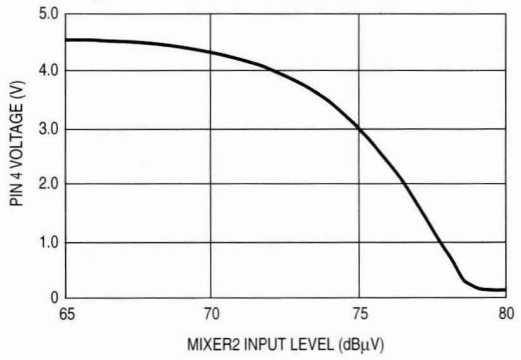



**Figure 5. RF AGC Voltage versus Mixer2 Input**

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**Pin 6 Current versus Mixer1 and Mixer2 Input Level:**

The internal resistance from Pin 6 to ground is 39 k. The RF AGC voltage on Pin 4 is 2.0 V when the voltage on Pin 6 is 1.2 V. Therefore, the desired AGC thresholds for either mixer can be set with these curves. The design steps are described in the design notes.

**Figure 6. Pin 6 Current versus Mixer1 Input Level**

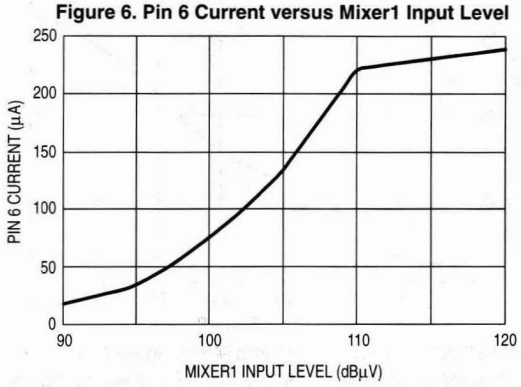
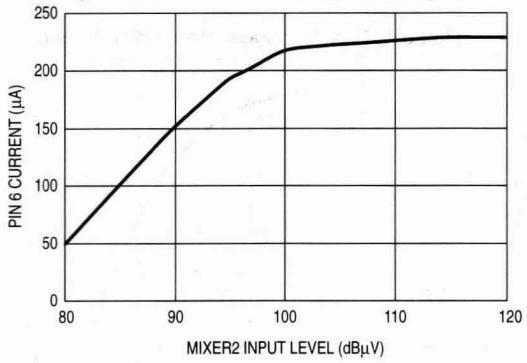


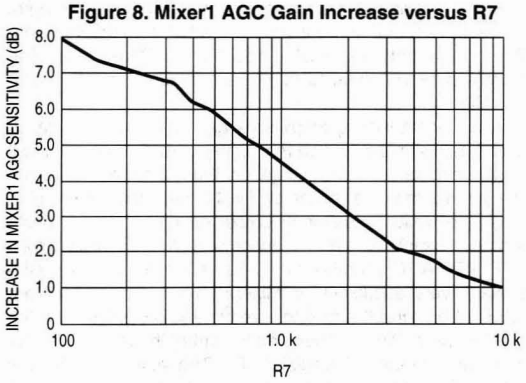

**Figure 7. Pin 6 Current versus Mixer2 Input Level**




**Mixer1 AGC Gain Increase versus R7:**

Adding a resistor from Pin 7 to ground increases the AGC sensitivity of Mixer1. The range of increase in dB can be found from this curve. This is useful after setting up the AGC threshold of Mixer2.

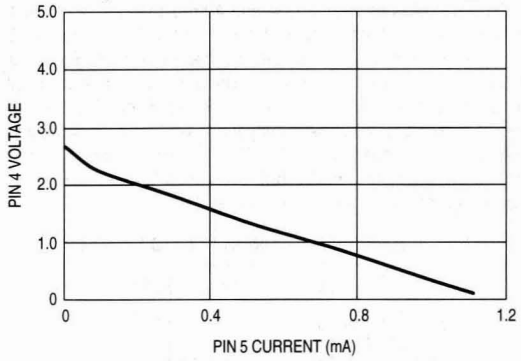
**Figure 8. Mixer1 AGC Gain Increase versus R7**




**Pin 5 Current versus Pin 4 Voltage:**

All the curves give Pin 4 AGC voltage versus some other input level. This curve can be used to determine the auxiliary AGC current from Pin 5 at a given Pin 4 voltage.

**Figure 9. Pin 5 Current versus Pin 4 Voltage**

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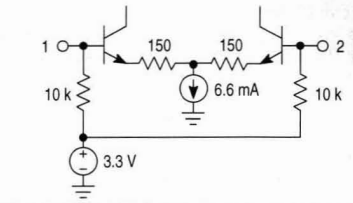
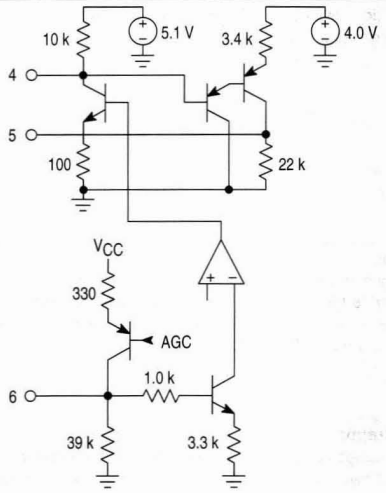
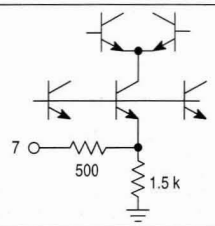
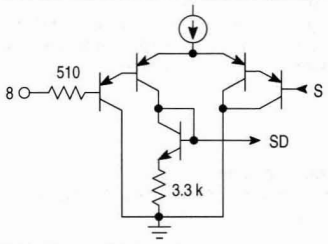
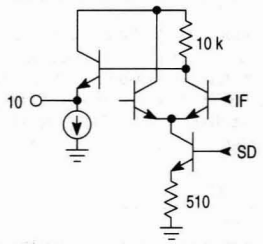
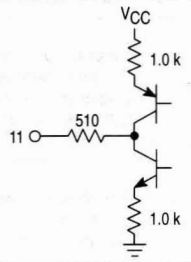
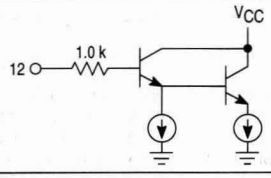
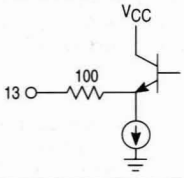
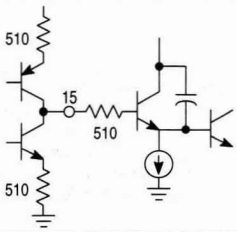
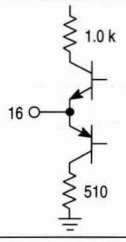
## PIN FUNCTION DESCRIPTION

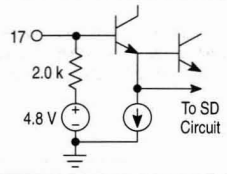
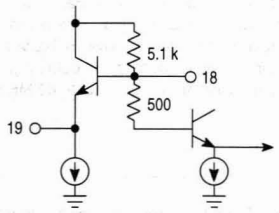
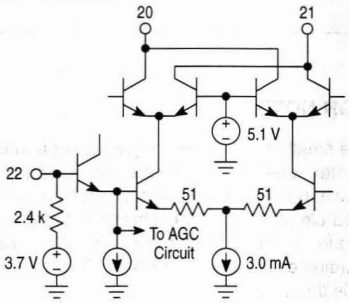
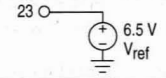
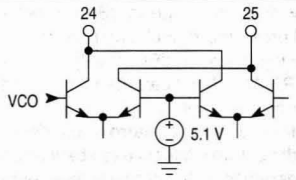
| Pin No. | Internal Equivalent Circuit | Description |
|---|---|---|
| 1, 2 |  | **Mixer1 Input**<br>Pins 1 and 2 are equivalent. In the application circuit, 2 is grounded with a capacitor and 1 is the input. If a load resistor is needed for the input filter, it can be placed across Pins 1 and 2. Input impedance for each pin is 10 k. IP3 (third order intercept) at the input is 20 dBm (127 dBμ). To guarantee –50 dB IM3, the input level should not be greater than 3.5 dBm (103 dBμ) (150 mVrms). |
| 3 | | **RF Ground**<br>This should be connected to the ground used for the RF circuits. |
| 4 |  | **FET RF AGC Output**<br>This is the AGC for the cascode transistor connected to the RF amplifier FET. The no–signal voltage is 5.1 V. The voltage decreases with increasing input signals. A bypass capacitor and electrolytic capacitor must be added to filter out RF signals on the transistor and audio signals in the AGC signal. See Figures 4 and 5. |
| 5 | | **RF AGC2 Output**<br>The voltage on this pin starts at 0 and increases with increasing input signals. It is normally used to turn on diodes or a transistor connected across the antenna input and is AGC delayed until Pin 6 reaches 2.7 V. If the voltage on Pin 5 decreases below 2.0 V, the voltage on this pin will decrease from 3.1 down to about 1.5 V. The maximum output current is about 850 μA. |
| 6 | | **RF AGC Adjust**<br>An electrolytic capacitor of 1.0 μF must be connected to prevent audio modulation of the AGC circuits. If there is no resistor on this pin, the RF AGC starts at an input level to Mixer1 ≈ 40 mVrms or Mixer2 ≈ 2.0 mVrms. Connecting a resistor from Pin 6 to ground increases RF levels required for AGC to start. It should be used to set the desired AGC level of Mixer2. If a resistor is not connected to Pin 6, unwanted RF signals will cause the AGC to start at a very low level, and desired signals may be suppressed. |
| 7 |  | **Mixer1 RF Level Adjust**<br>A resistor from Pin 7 to ground will increase the gain of an amplifier from the input of Mixer1 to the AGC circuit. It can be used to set the RF AGC level of Mixer1. The minimum value of R7 is about 680 Ω. |
| 8 |  | **Station Detector Signal Level Adjust**<br>A voltage on Pin 8 will set the desired signal strength at which the SD IF Out on Pin 10 appears. The other input to this comparator is the S (signal strength) signal. If Pin 8 is grounded, a square wave of the 2nd IF (usually 450 of 455 kHz) is present with very small input levels. This output could also be used to drive an FM detector if desired. |
| 9 | | **IF Ground**<br>Pin 9 is the ground for the IF section. |

9

**PIN FUNCTION DESCRIPTION (continued)**

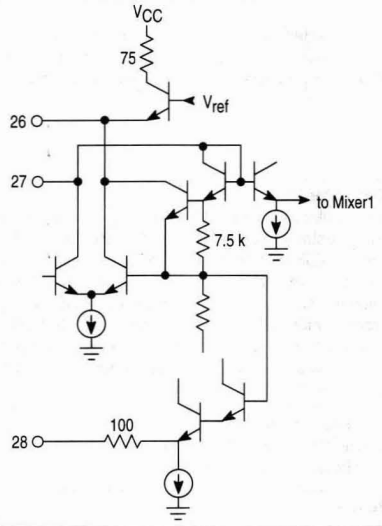
| Pin No. | Internal Equivalent Circuit | Description |
|---|---|---|
| 10 |  | **Station Detector IF Output**<br>This output is "on" when V11 > V8. The output is an amplified and limited 2nd IF signal. The signal level is ≈ 250 mVpp when it is 100% "on". |
| 11 |  | **S Level Output**<br>This is a dc current proportional to IF input level. With a load resistor of 75 k, the dc voltage is 0 to 5.1 V. |
| 12 |  | **IF AGC In**<br>The IF gain is controlled by the dc voltage on this pin. It is normally connected to Pin 13 through an RC network to filter out the audio signal on Pin 13. The IF gain is maximum when V13 ≈ 3.6 V. When V13 increases, the IF gain decreases. |
| 13 |  | **Audio Output**<br>The dc voltage on Pin 13 is ≈ 3.6 V with no input signal and increases to ≈ 4.5 V at minimum IF gain. A nonpolarized electrolytic capacitor may be required to couple to the audio circuits if the audio amplifier dc bias voltage is between these voltages. |
| 14 | | **Supply Voltage**<br>The nominal operating voltage is 8.0 V. |
| 15 |  | **IF Amplifier Output and Detector Input**<br>The detector coil must be connected between Pin 15 and 16. The IF amplifier output is a current source, the IF amplifier is a transconductance amplifier; the gain is determined by the impedance between Pins 15 and 16. The IF amplifier $g_m \approx 0.028$ mho. If a wide bandwidth IF is desired, the detector coil can be connected between Pins 15 and 16 without a tap and then loaded with a resistor across the coil. |
| 16 |  | **Detector Reference Voltage**<br>One side of the detector coil is connected to this pin. It should be bypassed with a 0.1 µF capacitor. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin No. | Internal Equivalent Circuit | Description |
|---|---|---|
| 17 |  | **IF Input**<br>The IF input impedance is 2.0 k to match most ceramic 455 or 450 kHz filters. For a ceramic filter requiring a 1.5 k load, a 5.6 k resistor in series with a 0.01 μF capacitor should be connected from Pin 17 to ground. |
| 18 |  | **Crystal Oscillator Base**<br>The crystal oscillator is a simple Colpitts type, operating at a low current. The crystal should operate at 10.250 MHz for 450 kHz IF or 10.245 MHz for 455 kHz IF with a 20 pF load capacitance. The oscillator signal to the second mixer is coupled from Pin 18 through an emitter follower. If a synthesizer such as the Motorola MC145170 with a 15 bit programmable R counter is used, the 10.245 MHz crystal can be connected to the synthesizer, and a 200 mVpp oscillator signal from the synthesizer can be capacitively coupled to Pin 18, so only one crystal is needed. |
| 19 | | **Crystal Oscillator Emitter**<br>The capacitive divider from Pin 18 is connected as shown in the application circuits of Figures 10, 11, 12. |
| 20, 21 |  | **Mixer2 Output**<br>The maximum AC collector voltage is about 5.8 Vpp or 2.0 Vrms. The mixer conversion transconductance $g_C$ = 0.0046 mho. The load impedance should be selected so the mixer output does not overload before the input. |
| 22 | | **Mixer2 Input**<br>The input impedance is 2.4 k. A series R–C network from Pin 22 to ground or a resistor from the filter to Pin 22 can be used to properly match the filter. In most cases, a 10.7 MHz crystal filter can be connected to Pin 22 directly without any additional components. IP3 (third order intercept) at the input is 5.0 dBm (112 dBμ). To guarantee –50 dB IM3, the input level should not be greater than –20 dBm (87 dBμ) (22.7 mVrms). |
| 23 |  | **$V_{ref}$**<br>This is the main reference voltage for most of the circuits in the IC and should be bypassed with a 1.0 μF capacitor. |
| 24, 25 |  | **Mixer1 Output**<br>The maximum collector voltage is about 5.8 Vpp or 2.0 Vrms. The mixer conversion transconductance $g_C$ = 0.0022. The load impedance should be selected so the mixer output does not overload before the input. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| Pin No. | Internal Equivalent Circuit | Description |
|---|---|---|
| 26 |  | **VCO Reference**<br>The first oscillator coil is connected from Pin 26 to 27. Pin 26 must be bypassed to ground with a capacitor which has a low impedance at the oscillator frequency. This capacitor also will reduce the phase noise of the VCO. |
| 27 | | **VCO**<br>The VCO is a negative resistance type and has an internal level control circuit so a tapped coil or one with a secondary is not needed. The level is fixed at 0.8 Vpp so the oscillator signal does not modulate the tuning diode, thus keeping the distortion low. The oscillator stray capacitance is ≈ 12 pF and the tuned circuit impedance should be greater than 3.0 k to guarantee oscillation. Oscillator range is up to 45 MHz so it can be used for SW receivers. |
| 28 | | **VCO Out**<br>The output level is 240 mVrms (108 dBμ), high enough to drive any CMOS synthesizer. |

## AM CAR RADIO DESIGN NOTES

The MC13030 AM Radio IC is intended for dual conversion AM radios. In most cases, the 1st IF frequency ($F_{IF1}$) is upconverted above the highest input frequency. The first oscillator (VCO) is tuned by a synthesizer and operates at $F_{in} + F_{IF1}$. For the 530 to 1700 kHz AM band with a 10.7 MHz first IF, the VCO goes from 11.23 to 12.40 MHz. Therefore, $F_{max}/F_{min}$ for VCO is only 1.104, so one low–cost tuning diode can be used. Since the required tuning voltage range can be made less than 5.0 V, it may also be possible to drive the tuning diode directly or from the phase detector of the synthesizer IC, such as the Motorola MC145170, operating from 5.0 V, without using a buffer amplifier or transistor.

If the VCO is above the incoming frequency, the image frequency of the first mixer is at $f_{OSC} + F_{IF1}$. For the AM broadcast receiver, it is around 22 MHz, so a simple LPF can be used between the RF stage and Mixer1 input. However, if a LPF is used, an additional coil is still needed to supply the collector voltage of the RF amplifier. For this reason, a BPF filter was used in the application circuit instead, since it uses the same number of coils and gives better performance. It is simply a lowpass to bandpass conversion. The lowpass filter is designed to have a cutoff frequency equal to the desired bandwidth. In this case, it would be 1700 – 530 kHz = 1170 kHz. Then, it is transformed to be resonant at 949 kHz, the geometric mean of the end frequencies: $\sqrt{1700 \times 530} = 949$ kHz.

A balanced–to–unbalanced transformer is required at the output of both mixers. The first one is designed so that Mixer1 has enough gain to overcome the loss of the 10.7 MHz filter and so that the output of the mixer will not overload before the input. The primary impedance of the transformer is relatively low, and it may be difficult to control with commonly available 7.0 mm transformers because the number of primary turns is quite small. It would also require a large tuning capacitance. A better solution is to tune the secondary with a small capacitance and then use a capacitive divider to match the tuned circuit to the filter. This allows one transformer to be used for either a ceramic or crystal filter. The capacitors can be adjusted to match the filter. The recommended coil is made this way.

If the formula: $P_{in}$ = IP3 – DR/2 is used, the maximum input level to the mixer can be calculated for a desired dynamic range.

IP3 = 3rd order intercept level in dB (dBm or dBμ)

DR = dynamic range in dB between the desired signals and 3rd order intermodulation products

$P_{in}$ = input level in dBm or dBμ

The RF AGC level can then be adjusted so that $P_{in}$ does not exceed this level.

Whether or not a narrow bandwidth crystal or wide bandwidth ceramic filter is used between the first and second mixers depends on the receiver requirements. It is possible to achieve about 50 dB adjacent channel and IM rejection with a ceramic filter because of the wide dynamic range of the mixers. If more than this is required, a crystal filter should be used. If a crystal filter is used, a lower cost CFU type of 455 kHz second IF filter can be used. If a ceramic filter is used, a CFW type filter should be used because there is no RF section selectivity in this type of radio.

Since the wideband AGC system is quite sensitive, it can be set to eliminate all spurious responses present at the receiver output. However, the RF AGC will sometimes eliminate or reduce the level of desired signals if there is a strong signal somewhere in the bandpass of the RF circuit.

The second mixer is designed like the first and requires a balanced output. Since its load impedance is higher, the transformer can be designed to be tuned on the primary or

secondary, but, like with the one for the first mixer, if the secondary is tuned, the tap can be adjusted for the impedance of the 455 kHz filter. Wideband filters usually have a higher terminating resistance than the narrowband ones. The recommended coil is made this way.

The IF amplifier is basically a transconductance amplifier because the output is a current source. The output is also internally connected to a high impedance AM detector. $g_m$ for the IF amplifier is ≈ 0.028 mho. The voltage gain will be the detector coil impedance x 0.028. This can be designed to give the desired audio output level for a given RF input level. If it is set too high, the receiver may oscillate with no input signal. The application circuit was designed for a relatively narrow bandwidth, so a tapped detector coil is used to get the desired gain. If a wide bandwidth receiver is desired, the detector coil can be untapped, and a resistor can be added across the coil to get the desired Q.

The detector output on Pin 13 is a low impedance. It supplies the IF AGC signal to Pin 12, so the audio must be filtered out. The time constant of this filter is up to the designer. The main requirement is usually the allowable audio distortion at 100 Hz, 80% modulation. If the time constant is made too long, the audio level will be slow to correct when changing stations.

The Signal Strength (S) output is dependent only on the IF amplifier input level. Its maximum voltage is about 5.0 V with a 75 k load resistor. The range can be reduced by using a lower value for the resistor on Pin 11. The S signal will stop increasing when the RF AGC circuits become active, so if the RF AGC threshold is set too low, or there is too much loss from the Mixer2 output to the IF input, the maximum S signal will be reduced. The desired load resistor on Pin 11 (R11) can be determined using the curve of Pin 11 current versus IF input.

Setting the RF AGC threshold is probably the most difficult because a trade–off between allowable interference and suppression of desired signals must be made.

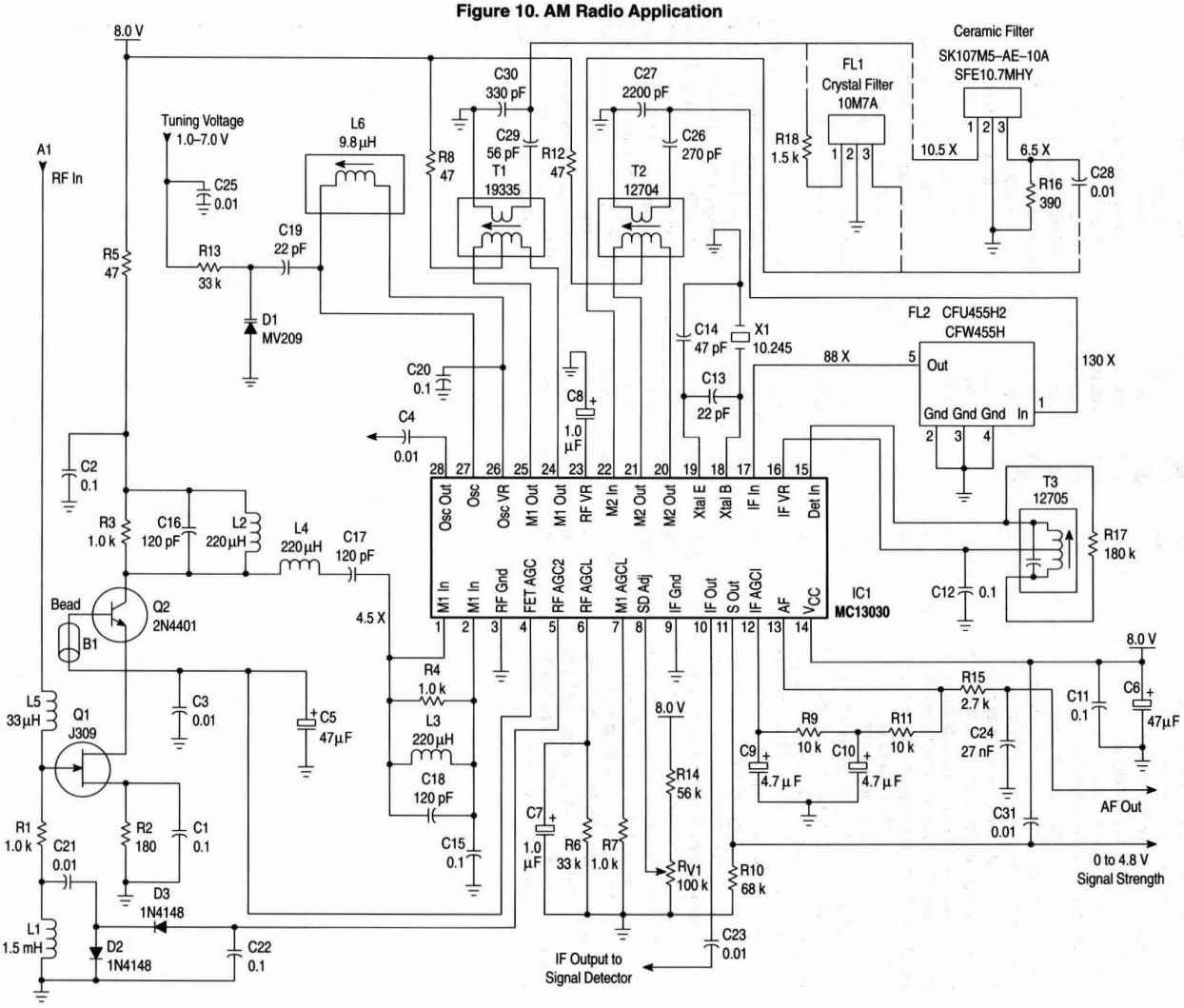
First select the values for both mixers:

d. Using the formula $P_{in} = IP3 - DR/2$
   Select the desired dynamic range and calculate the maximum input levels for both mixers. Remember that all levels must be in dB, dBμV or dBm. Let DR = 50 dB. IP3 for Mixer2 = 112 dBμV. Therefore, $P_{inmax}$ = 87 dBμV. IP3 for Mixer1 = 127 dBμV. Therefore, $P_{inmax}$ = 102 dBμV.
e. First, adjust the resistor from Pin 6 to ground to give the desired maximum input level to Mixer2. From the curve of Pin 6 current versus Mixer2 input level, R6 = 1.2/110 μA = 11 k. $R_{int}$ = 39 k, so $R_{6ext}$ = 15 k.
f. From the curve of Pin 6 current versus Mixer1 input level, determine how much more gain would be required in the Mixer1 AGC circuit to achieve the desired dynamic range for Mixer1. From the curve of Relative Sensitivity versus R7 determine the value of R7. Alternatively, R7 can be adjusted to give the desired maximum input level to Mixer1.

The resulting R7 may be too small to set the AGC threshold of Mixer1 as low as desired. Also, if R7 is less than 680 Ω, the AGC sensitivity for the Mixer1 input falls off at higher frequencies, so in these cases, the resistor from Pin 6 to ground must be reduced to achieve the desired level because the overload of Mixer1 provides the most important spurious response rejection. However, if the AGC level is set too high, the IF in signal may become too large and the IF amplifier can overload with strong signals. The values used in the application are more conservative.

The gain from the antenna input to the point being measured are shown on the AM radio application. These are helpful when calculating audio sensitivity and troubleshooting a new radio.

**Figure 10. AM Radio Application**



## SW RADIO DESIGN NOTES

The shortwave receiver was designed to cover from 5.0 to 10 MHz. This MC13030 radio has better performance than most receivers because of the high dynamic range and spurious rejection of the mixers.

The RF stage bandpass filter for this radio is the same type as the one used for the car radio, but the series tuned section was scaled down in impedance to reduce the inductance of the coil.

Since most SW receivers include an SSB and CW mode, the detector coil could have a secondary winding to supply the second IF signal to this section.

The capacitors C10 and C23 have been reduced from those in the AM radio so that the AGC system can follow variations in signal level due to fading.

## CB RADIO DESIGN NOTES

The RF stage bandpass filter for this radio consists of a tuned input and a double tuned interstage filter. For lower cost radios, a single tuned interstage filter could be used.

The schematic also shows a crystal 10.7 MHz 1st IF filter, but a ceramic or coil filter could also be used. An intermodulation rejection of 50 dB can be obtained with a ceramic 1st IF filter.

A bipolar transistor is shown for the RF stage. A dual gate CMOS FET could also be used with G2 connected to the AGC voltage on Pin 4. A PIN diode is recommended for D2.

## COIL DATA

T1 – Toko A119ANS–19335UH

T2 – Toko A7MNS–12704UH

T3 – Toko A7MCS–12705Y

**Figure 11. 5 to 10 MHz Radio Application**

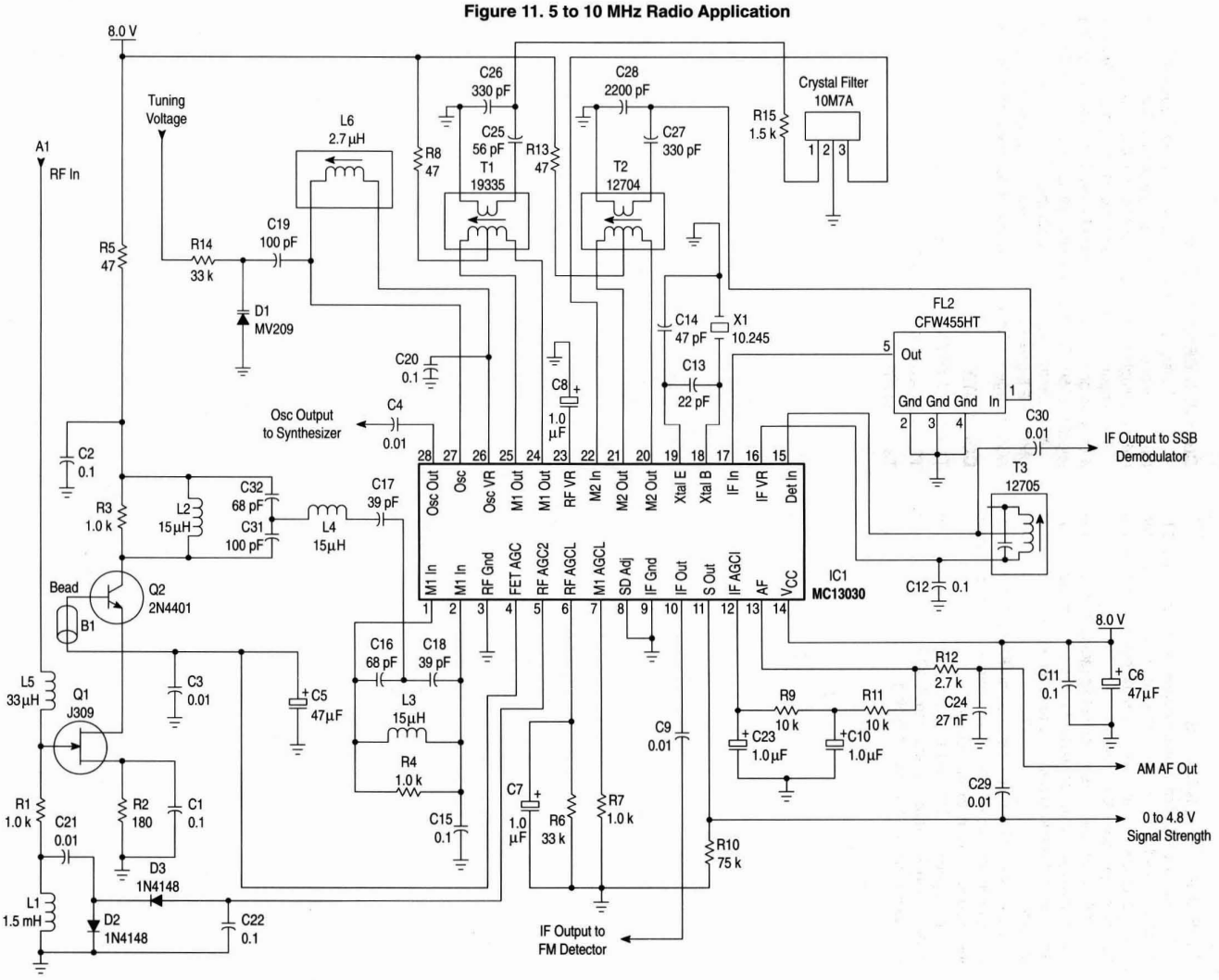


**Figure 12. CB Radio Application**

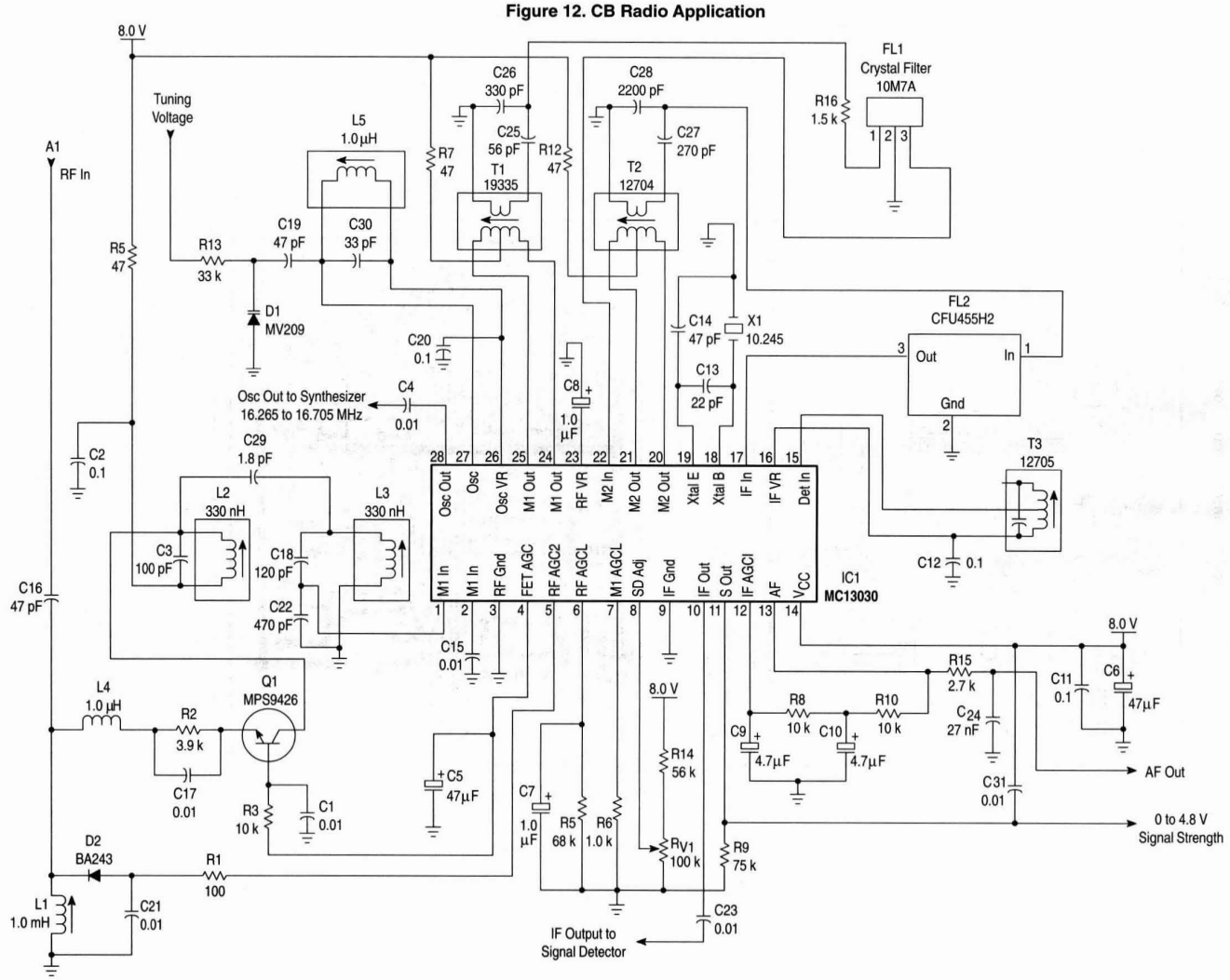
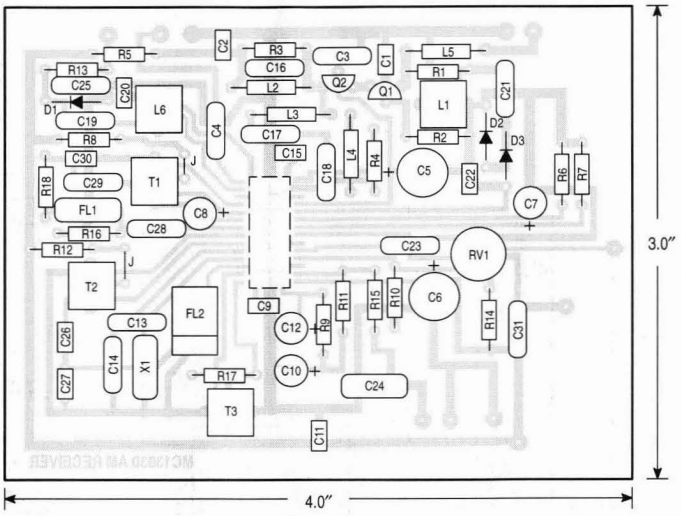
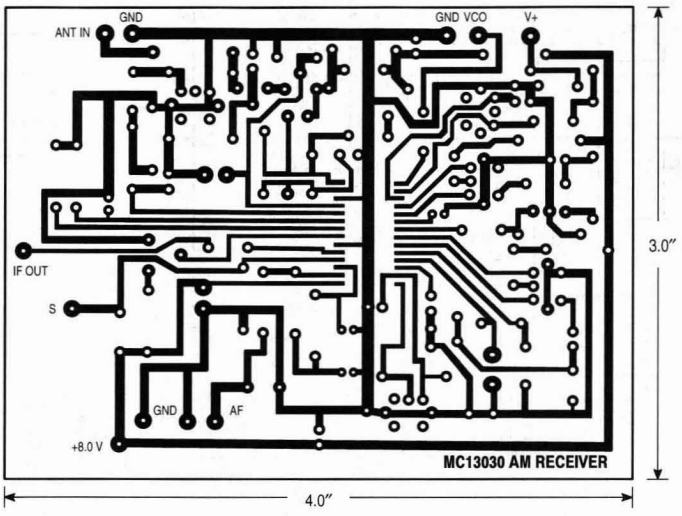


**Figure 13. Printed Circuit Board**




(Top View)

**NOTE:** J = Jumper




(Bottom View)

MOTOROLA

# MC13060

# Mini-Watt Audio Output

This device is a rugged and versatile power amplifier in a remarkable plastic power package.

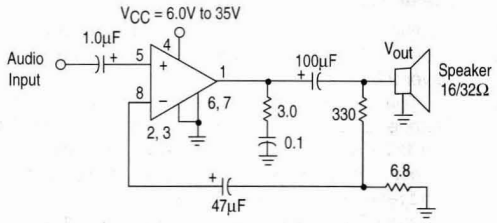
- Supply Voltages from 6.0 Vdc to 35 Vdc
- 2.0 W Output @ 70°C Ambient on PC Board with Good Copper Ground Plane
- Self Protecting Thermal Shutdown
- Easy to Apply, Few Components
- Gain Externally Determined
- Output is Independent of Supply Voltage Over a Wide Range

**MINI–WATT AUDIO OUTPUT**

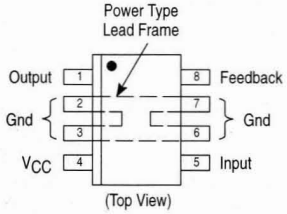
**SEMICONDUCTOR TECHNICAL DATA**

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SOP–8)

**Figure 1. Simplified Application**



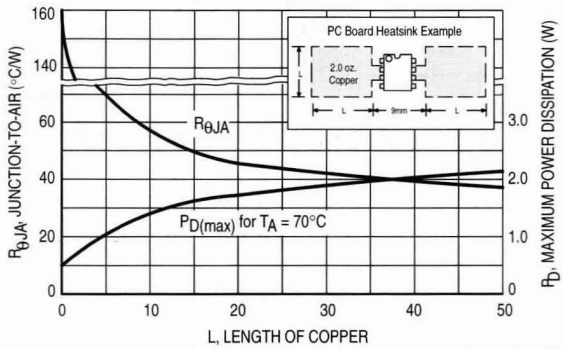

**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13060D | $T_A$ = – 40 to +85°C | SOP–8 |

**Figure 2. Thermal Resistance & Maximum Power Dissipation versus PC Board Copper**




9

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | 35 | V |
| Audio Input, Pin 5 | | 1.0 | $V_{pp}$ |
| Thermal Resistance, Junction to Air | $R_{\theta JA}$ | 160 | °C/W |
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 25 | °C/W |
| Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, circuit of Figure 3, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **AUDIO SECTION** | | | | | |
| Power Supply Current, No Signal | $I_{CC}$ | – | 13 | – | mAdc |
| Gain | $A_o$ | – | 50 | – | V/V |
| Distortion at 62.5 mW Output, 1.0 kHz | THD | – | 0.2 | 1.0 | % |
| Distortion at 900 mW Output, 1.0 kHz | THD | – | 0.5 | 3.0 | % |
| Quiescent Output Voltage, No Signal | $V_{Pin\ 1}$ | – | 8.4 | – | Vdc |
| Input Bias | $V_{Pin\ 5}$, $V_{Pin\ 8}$ | – | 0.7 | – | Vdc |
| Input Resistance | $R_{in}$, Pin 5 | – | 28 | – | kΩ |
| Output Noise (50 Hz to 15 kHz) Input 50 Ω | $V_{out}$ | – | 0.5 | 4.0 | mVrms |

## GENERAL DESCRIPTION

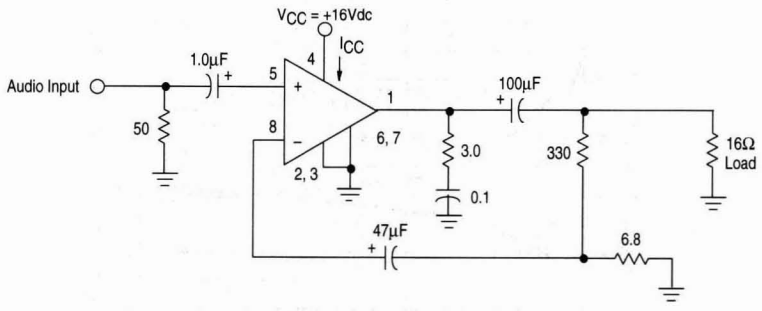
The MC13060 is a quasi–complementary audio power amplifier, mounted in the SOP 8 (power SOIC package). It is well suited to a variety of 1.0 W and 2.0 W applications in radio, TV, intercom, and other speaker driving tasks. It requires the usual external components for high frequency stability and for gain adjustment.

The output signal voltage and the power supply drain current are very linearly related, as shown in Figure 5. Both are quite constant over wide variation of the power supply voltage (above minimum $V_{CC}$ for clipping, of course). The amplifier can best be described as a voltage source with about 1.0 $A_{pp}$ capability. On a good heatsink, it can deliver over 2.0 W at 70°C ambient.

The MC13060 will automatically go into shutdown at a die temperature of about 150°C, effectively protecting itself, even on fairly stiff power supplies. This eliminates the need for decoupling the power supply, which degrades performance and requires extra components.

Input Pins 5 and 8 are internally biased at 0.7 Vdc and should not be driven below ground.

**Figure 3. Test Circuit**



**All Curves Taken in the Test Circuit of Figure 3, Unless Otherwise Noted.**

**Figure 4. Quiescent Supply Current and Output Voltage versus Supply Voltage**

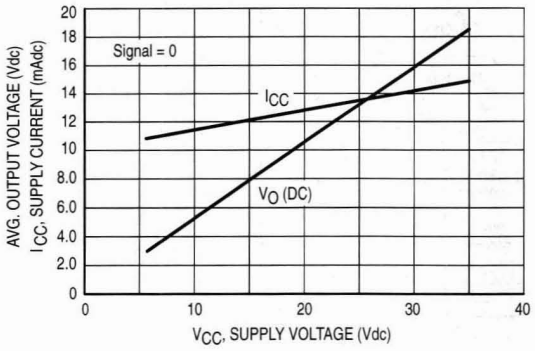



**Figure 5. Supply Current versus Output**

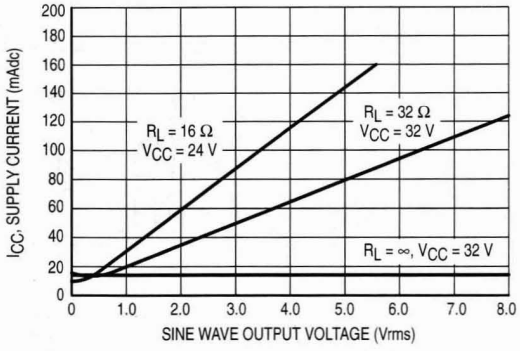



**Figure 6. Distortion and Gain versus Frequency**

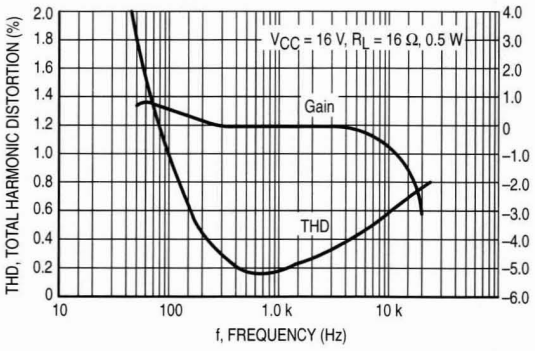



**Figure 7. Distortion versus Power Output**

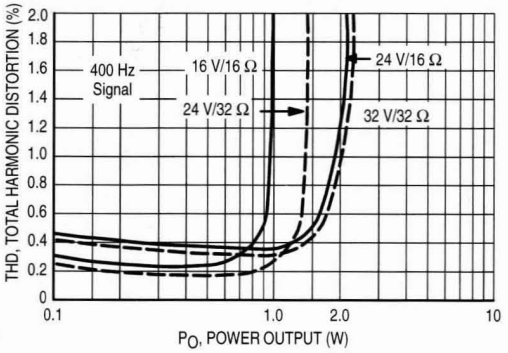



**Figure 8. Dissipation versus Output Power**

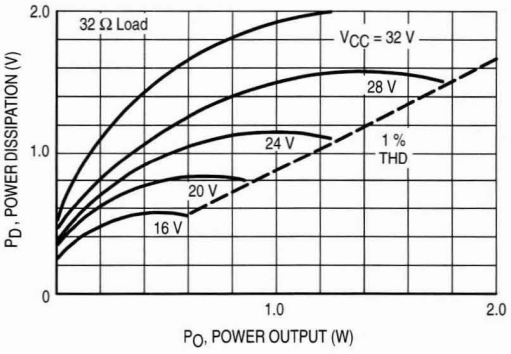
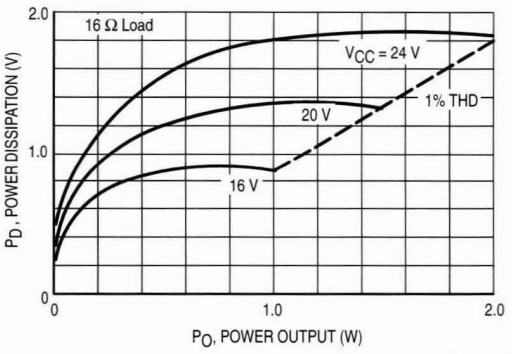
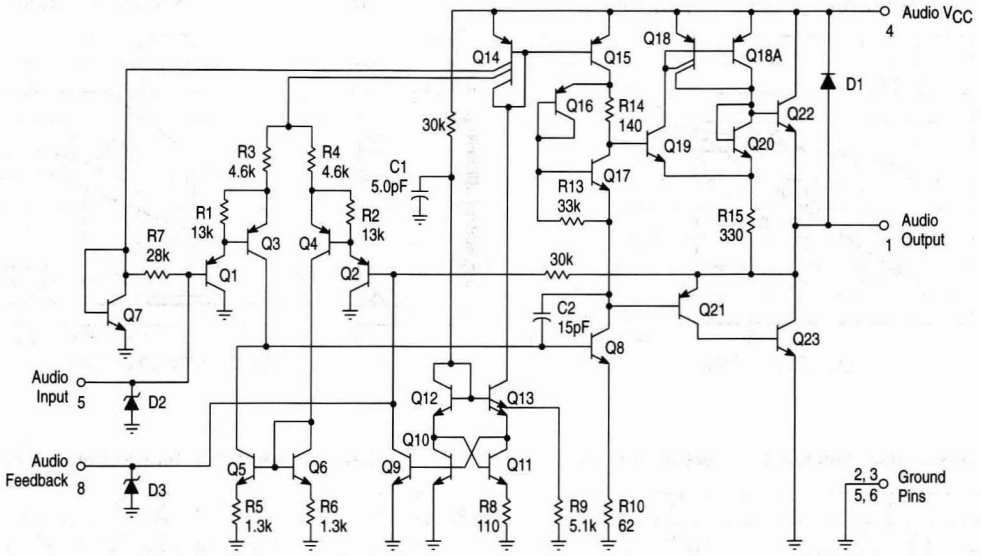



**Figure 9. Dissipation versus Output Power**




9

**Figure 10. Representative Schematic Diagram**




9

MOTOROLA

# MC13077

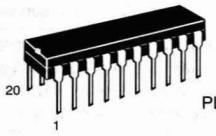
# Advanced PAL/NTSC Encoder

The MC13077 is a high quality RGB/YUV to NTSC/PAL encoder with Composite Video and S–Video outputs. The IC integrates the color difference and luma matrix circuitry, chroma modulators, subcarrier oscillator, and logic circuitry to encode component video into a composite video signal compatible with the NTSC/PAL standards. The IC operates off a standard +5.0 V supply and typically requires less than 75 mA, making it useful in PC environments. The high degree of integration saves board space and cost, as only passive external components are required for operation. The IC is manufactured using Motorola's MOSAIC™ process and is available in a 20 pin DIP or SOIC package.

- Single 5.0 V Supply
- Composite Output
- S–Video Outputs
- PAL/NTSC Switchable
- PAL Squarewave Output
- PAL Sequence Resettable
- Internal/External Burst Flag
- Digitally Determined Modulator Axes
- Subcarrier Reference Drive Selectable

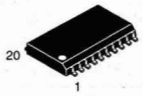
**ADVANCED PAL/NTSC ENCODER**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 738

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13077DW | $T_A$ = 0° to +70°C | SO–20L |
| MC13077P | | Plastic DIP |

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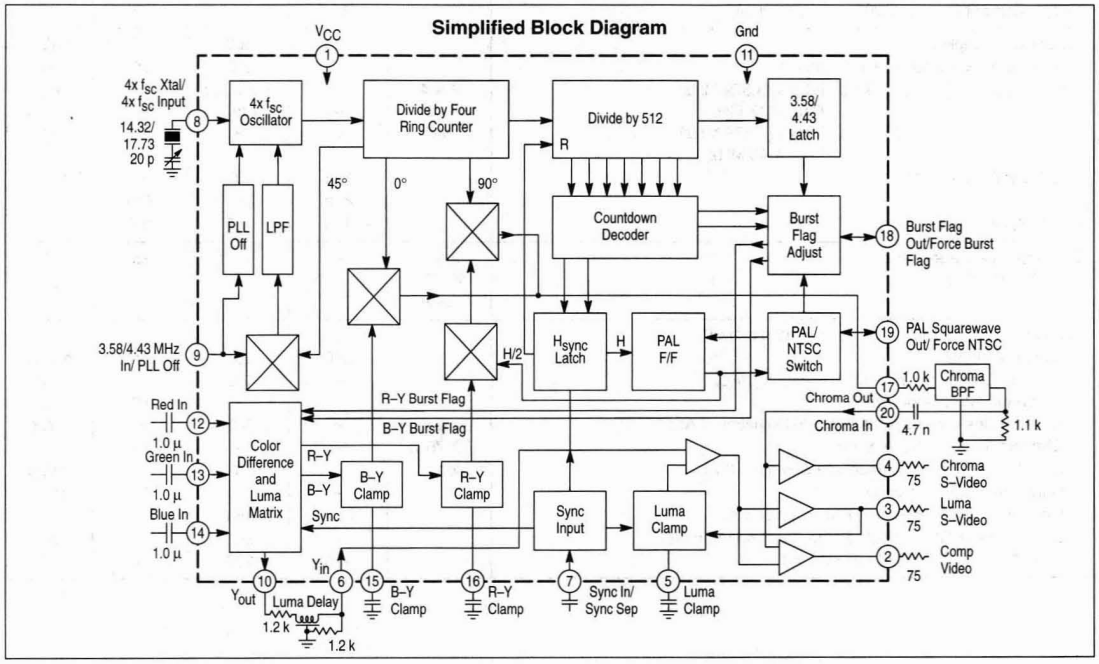
**Simplified Block Diagram**



## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 6.0 | V |
| Storage Temperature | $T_{stg}$ | – 65 to +150 | °C |
| Operating Junction Temperature | $T_J$ | +150 | °C |
| Operating Ambient Temperature | $T_A$ | 0 to + 70 | °C |

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Supply Voltage | 4.5 | 5.0 | 5.5 | Vdc |
| Sync Input Threshold Equivalent (See Figure 2) | – | 1.4 | – | Vdc |
| Pulse Width | – | 4.5 – 5.5 | – | µs |
| R, G, B Input (Amplitude for 100% Saturated Video) | – | 0.7 | – | Vpp |
| R–Y Input Amplitude at Pin 16 (for 100% Saturated Video) | – | 490 | – | mVpp |
| B–Y Input Amplitude at Pin 15 (for 100% Saturated Video) | – | 350 | – | |
| Y Input Amplitude (without sync) at Pins 12, 13, 14 (for 100% Saturated Video) | – | 700 | – | |
| Y Input Amplitude (with sync) at Delay Line | – | 1.0 | – | Vpp |
| External 4x Subcarrier Input to Pin 8 (If crystal is not used) | – | 300 | – | mVpp |
| External Subcarrier Input to Pin 9 | – | 0.10 to 3.0 | – | Vpp |
| Lock Range (with 4x Subcarrier Crystal specified) at Subcarrier Frequency | – | ± 400 | – | Hz |
| Burst Flag Input Threshold (Pin 18) | – | 2.5 | – | Vdc |
| NTSC/PAL Select (Pin 19) | | | | Vdc |
| PAL Switching Amplitude: High | – | 4.0 | – | |
| Low | – | 1.1 | – | |
| NTSC Select Threshold | – | 0.4 | – | |

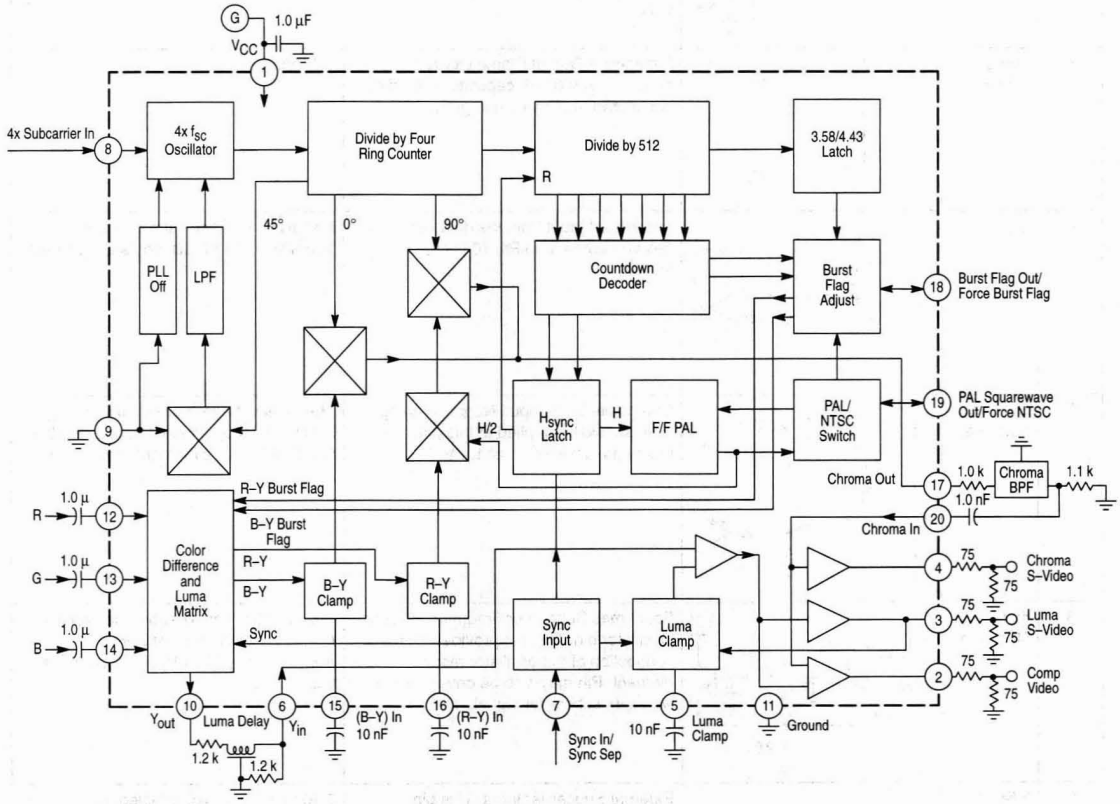
## ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc, test circuit of Figure 1.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current (150 Ω Load on Output Pins) | 1 | 55 | 70 | 85 | mA |
| Color Burst Amplitude | | 250 | 300 | 350 | mVpp |
| Line–to–Line Burst Amplitude Deviation | | – | 7.0 | 25 | mV |
| Start after leading edge of Sync: NTSC (3.579 MHz) | 2 & 4 | – | 5.0 to 5.3 | – | µs |
| PAL (4.43 MHz) | (@ 75 Ω | – | 5.4 to 5.6 | – | |
| Duration: NTSC (3.579 MHz) | load) | – | 9 | – | Cycles |
| PAL (4.43 MHz) | | – | 10 | – | |
| PAL Burst Phase: Line n | | 125 | 135 | 145 | Degrees |
| Line n+1 | | 215 | 225 | 235 | |
| NTSC Burst Phase | | 170 | 180 | 190 | |
| Subcarrier Leakage in Black | 2 & 4 | – | – | 25 | mV |
| White (100% white) | (@ 75 Ω load) | – | – | 65 | |
| Composite Video Output (100% saturated output) | | | | | |
| Sync Amplitude | | 240 | 281 | 320 | mVpp |
| Line–to–Line Sync Amplitude Deviation (PAL) | | – | 7.0 | – | mV |
| Luminance Amplitude Error | | – | – | 10 | % |
| Line–to–Line Luminance Amplitude Deviation (PAL) | 2 | – | 3.0 | – | mVpp |
| Chrominance Amplitude Error | (@ 75 Ω | – | – | 10 | % |
| Line–to–Line Chroma Amplitude Deviation (PAL) | load) | – | < 14 | – | mVpp |
| Chrominance Phase Error | | – | – | 10 | Degrees |
| Line–to–Line Chrominance Phase Error (PAL) | | – | < 5.0 | – | |
| Black Level (RGB at Black during Blanking Intervals) | | – | 500 | – | mV |
| Sync Tip Clamp Level above Ground | | 120 | 200 | 280 | |

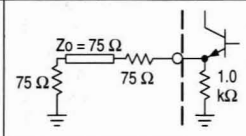
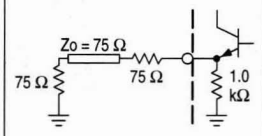
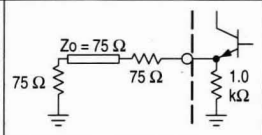
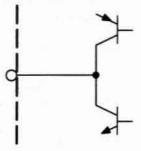
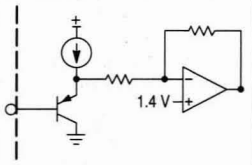
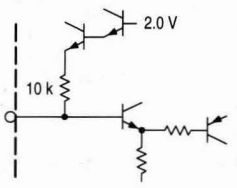
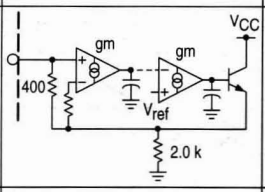
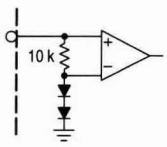
**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC}$ = 5.0 Vdc)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Luma S–Video Output | | | | | |
| Sync Amplitude | | 240 | 281 | 320 | mVpp |
| Line–to–Line Sync Amplitude Deviation (PAL) | 3 | – | 7.0 | – | mV |
| Luminance Amplitude Error | (@ 75 Ω | – | – | 10 | % |
| Line–to–Line Luminance Amplitude Deviation (PAL) | load) | – | 3.0 | – | mVpp |
| Black Level | | – | 500 | – | mV |
| Sync Tip Clamp Level above Ground | | 120 | 200 | 280 | |
| Chroma S–Video Output | | | | | |
| Chrominance Amplitude Error | | – | – | 10 | % |
| Line–to–Line Chrominance Amplitude Deviation (PAL) | 4 | – | < 14 | – | mVpp |
| Chrominance Phase Error | (@ 75 Ω | – | – | 10 | Degrees |
| Black Level | load) | – | 500 | – | mV |

**Figure 1. Test Circuit**



## PIN DESCRIPTIONS

| Pin | Symbol | Internal Equivalent Schematic | Description | Expected Waveforms |
|---|---|---|---|---|
| 1 | $V_{CC}$ | | Supply Voltage | + 5.0 Vdc ±10% |
| 2 | Comp Video |  | Composite Video output. The external 75 Ω series resistor determines the impedance of the output. The output will drive a 75 Ω load through a 75 Ω coax. | 1.0 Vpp (75% Color Saturation), 1.23 Vpp (100% Color Saturation) at the 75 Ω load. |
| 3 | Luma S–Video |  | Luminance S–Video output. The external 75 Ω series resistor determines the impedance of the output. The output will drive a 75 Ω load through a 75 Ω coax. | 1.0 Vpp with sync (100% output) at the 75 Ω load. |
| 4 | Chroma S–Video |  | Chrominance S–Video output. The external 75 Ω series resistor determines the impedance of the output. The output will drive a 75 Ω load through a 75 Ω coax. | 885 mVpp (100% output) when at the 75 Ω load. |
| 5 | Luma Clamp |  | Luminance Output Clamp storage capacitor. A 0.01 µF capacitor should be connected from this pin to ground. | 3.4 Vdc. |
| 6 | $Y_{In}$ |  | Luminance input from the delay line. The delayed Luma from Pin 10 is applied at this pin. | 500 mVpp of Composite Luma when 100% saturated RGB inputs are applied. |
| 7 | Sync In/ Sync Sep |  | Composite Sync input. Negative going sync should be applied at this pin. The input has a threshold of 1.4 V. | The peak voltage may not exceed $V_{CC}$. Minimum voltage should not be less than 0 V. See Figure 2 for input requirements. |
| 8 | 4x $f_{SC}$ Xtal /4x $f_{SC}$ In |  | Four times Subcarrier Frequency Crystal Oscillator pin. This pin provides for the connection of the oscillator resonant element. Pin may also be driven directly with a 4x subcarrier signal. | 300 to 600 mVpp 4x subcarrier input if the pin is being externally driven. Approximately 40 mVpp, if a crystal is being used. |
| 9 | 3.58/ 4.43 MHz In/PLL Off |  | External Subcarrier Input. This pin provides an input to a Phase Detector and PLL and allows phase–lock of the 4x oscillator to an external subcarrier reference. To disable the PLL, this pin should be grounded. 400 Hz of pull–in and lock–in range is possible with a crystal. | 0.10 to 3.0 Vpp (AC coupled) of subcarrier to phase–lock 4x oscillator or grounded to disable the PLL. |

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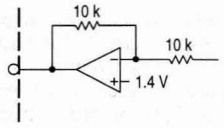
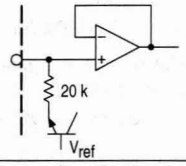
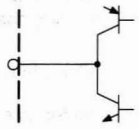
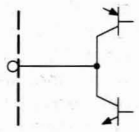
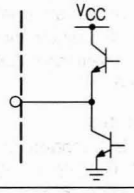
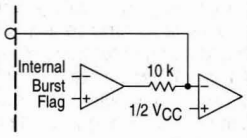
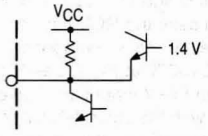
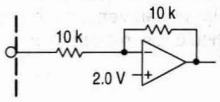
**PIN DESCRIPTIONS (continued)**

| Pin | Symbol | Internal Equivalent Schematic | Description | Expected Waveforms |
|---|---|---|---|---|
| 10 | $Y_{Out}$ |  | Luminance Delay Line Drive Output. A delay should be inserted between this pin and Pin 6 to match the delay incurred by the Chroma. | 1.0 Vpp with sync (100% saturated Color Bar output). |
| 11 | Gnd | | Ground | Ground |
| 12 | $Red_{In}$ |  | Red Video input. | 0.7 Vpp AC coupled (100% Color Bars). |
| 13 | $Green_{In}$ | See Pin 12 | Green Video input. | 0.7 Vpp AC coupled (100% Color Bars). |
| 14 | $Blue_{In}$ | See Pin 12 | Blue Video input. | 0.7 Vpp AC coupled (100% Color Bars). |
| 15 | B–Y Clamp |  | B–Y Clamp storage capacitor. A 0.01 µF capacitor should be connected from this pin to ground, unless the pin is used as an input. | If not used as an input the pin is clamped during sync to 2.4 Vdc. Can be used as a B–Y input (AC coupled, 350 mVpp, 100% color saturation). Burst Flag, if disabled at Pin 18, must be inserted here with the following signal levels; –170 mV (NTSC), –121 mV (PAL). |
| 16 | R–Y Clamp |  | R–Y Clamp storage capacitor. A 0.01 µF capacitor should be connected from this pin to ground, unless the pin is used as an input. | If not used as an input the pin is clamped during sync to 2.4 Vdc. Can be used as a R–Y input (AC coupled, 490 mVpp, 100% color saturation). Burst Flag, if disabled at Pin 18, must be inserted here with the following signal level; +121 mV for PAL. |
| 17 | Chroma Out |  | Chroma Bandpass Drive Output. | 2.8 Vpp (100% Color Bars) |
| 18 | Burst Flag Out/Force Burst Flag |  | Burst Flag Output Disable and Force pin. If left unconnected, internally generated color burst will appear at Pins 2 and 4. Burst Flag will appear at this pin (18). If grounded, the Burst Flag will be disabled. If externally driven from another source of burst flag, the internal flags will be overriden. | 1.8 Vpp burst flag pulses if unconnected. |
| 19 | PAL Square–wave Out/Force NTSC |  | PAL/NTSC system switch. If grounded, the MC13077 will encode NTSC, and if left open, PAL. | In PAL mode, a PAL squarewave appears at this pin, the phase of which can be reset by momentarily forcing the pin to ground during the high state of the squarewave. |
| 20 | Chroma In |  | Chroma Bandpass input. Output from chroma bandpass filter should be applied at this pin. | 1.4 Vpp (100% Color Bars) with bandpass filter and 1.0 kΩ matching resistors. |

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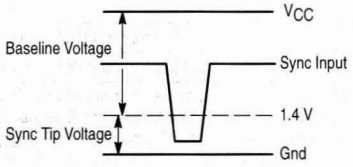
## FUNCTIONAL DESCRIPTION

### Composite Sync Input

Other than the component video inputs to be encoded, only Composite Sync is required for encoding the components into a composite signal compatible with either the NTSC or PAL standard. The Composite Sync input is used internally for determining which standard to encode to, for driving the black level clamps, and to set the timing of the composite sync in the outputs.

The Composite Sync/Sync Separator input was designed to accept AC or DC coupled inputs making it possible to drive the sync input from a variety of sources. An interesting note is that composite video can also be used for sync input. The threshold of the sync input is 1.4 Vdc. Figure 2 shows the requirements for sync input.

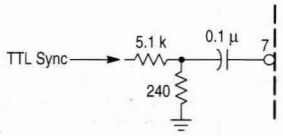
**Figure 2. Sync Input Amplitude Requirements**




Both serrated and block vertical sync can be used for NTSC applications. PAL applications require a serrated vertical sync. The serrations at the horizontal rate trigger the PAL flip–flop to generate the swinging burst.

Even though the sync input of the MC13077 is well suited for TTL interface, some functions of the IC are susceptible to the high energy present in such signals and may be disturbed. This disturbance may take the form of a noise spike in the video outputs and/or a disturbance of the 4x oscillator resulting in an incorrect encoding of the chroma information. Therefore, it is recommended that if TTL or other fast–edged inputs are going to be used for the sync input, then either the amplitude and/or the edge speed of the sync input pulse should be reduced. 300 mVpp of sync without a reduction of edge speed has to be shown to produce disturbance free operation. Also, a sync input of 4.0 Vpp and edge rates of 225 ns have been shown to produce similar results. Figure 3 shows a recommended coupling circuit for TTL type composite sync.

**Figure 3. TTL Sync Input Circuit**




### Luma and Color Difference Clamps

Clamping for the MC13077 occurs once every horizontal line during sync. The absence of color creates a color difference component voltage of zero, this null is used to generate a reference voltage for black in the video outputs. The clamp capacitors at Pins 5, 15 and 16 are used to store the reference voltage during the line period.

### RGB Inputs

To encode RGB, the component video inputs (Pins 12, 13, 14) are applied to the Luma (Y) and color difference (R–Y, B–Y) matrix. The color difference signals are then conditioned by Sallen–key low pass filters (f–3dB = 4.0 MHz). The inputs are designed so that 700 mVpp RGB provides 100% color saturation.

The first color difference component (R–Y) is created by matrixing the RGB components with the following weights:

$$R–Y = 0.70R – 0.59G – 0.11B \quad (1)$$

The second color difference signal (B–Y) is created in a similar fashion by the equation:

$$B–Y = 0.89B – 0.59G – 0.30R \quad (2)$$

These two components then receive burst flag before being modulated by the color subcarrier to create composite chroma.

The luma is also the result of a weighted matrixing of the RGB components. The components and corresponding weights are:

$$Y = 0.30R + 0.59G + 0.11B \quad (3)$$

Composite sync is then added to the result of Equation 3 to create composite luma.

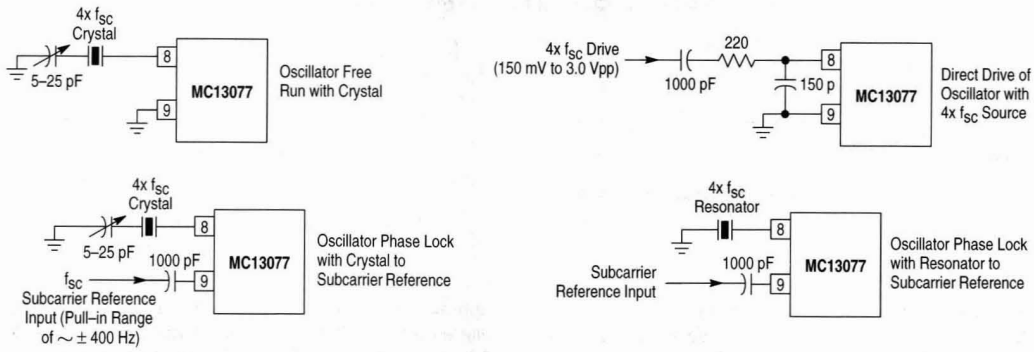
The luma information thus created must be eventually recombined with the chroma information. However, since the chroma information created by Equations 1 and 2 is filtered internally before being modulated then bandlimited externally, the resultant encoded chroma experiences a group delay that is the sum of the delay imposed by the internal and external filtering. So, the composite luma is output at Pin 10 so that an external delay can be inserted in the path to match the delay incurred by the composite chroma. The delayed composite luma is then input back into the MC13077 at Pin 6.

### Color Difference Inputs

If the MC13077 is intended to encode color difference signals (YUV or Y, R–Y, B–Y), it becomes necessary to bypass the color difference and luma matrix circuitry. This can be accomplished by inputing directly to the color modulators the color difference signals. 491 mVpp and 349 mVpp should be input to the R–Y and B–Y Clamp pins (Pin 16 and Pin 15) respectively, to achieve 100% color saturation in the composite video output. The luma information can be input in two ways. The luma can be input directly into the RGB inputs (700 mVpp without sync), or through the delay line (1.0 Vpp with sync, sync tip–to–peak white) in which case the RGB inputs should be cap–coupled to ground. In either case, composite sync still needs to be input to the MC13077 at Pin 7 (see Figures 11, 12 and 13).

If the R–Y and B–Y inputs also have burst flag, it can also be input along with the color difference signals at these pins. Of course, now since the color difference modulator pre–filtering is circumvented, the delay for the luma information should be matched only to the delay of the bandpass filter.

**Figure 4. Versatility of the 4x $f_{SC}$ Oscillator**




### 4X Subcarrier Oscillator

To encode the color difference components, an accurate and reliable subcarrier source is required. The MC13077 has an on–chip single pin oscillator that will free–run with a 4x $f_{SC}$ crystal, phase–lock to an external subcarrier reference with a 4x $f_{SC}$ crystal or resonator, or be driven externally from a 4x $f_{SC}$ source. If the 4x $f_{SC}$ oscillator is going to be free run, the subcarrier input (Pin 9) should be grounded. If the 4x $f_{SC}$ oscillator is going to be phase–locked to an external subcarrier source, the external reference should be capacitor–coupled to Pin 9. If the 4x $f_{SC}$ oscillator is going to be driven externally, Pin 8 should be driven from a network that increases the impedance of the source at frequencies capable of producing off–frequency oscillations. The 4x $f_{SC}$ subcarrier source, thus being defined, makes it possible to produce accurate quadrature subcarriers for the modulators. The 4x source is internally divided by a ring counter to produce the quadrature subcarrier signals. These signals in turn are provided to the color difference modulators to produce the modulated chroma. The oscillator was designed so that if a crystal is chosen as the resonant element of the 4x oscillator, the crystal specifications would be common. Crystal specifications for an adequate crystal are shown in 1

**Table 1. Crystal Specifications**

| |
|---|
| Frequency: 14.31818 MHz (NTSC)<br>17.734475 MHz (PAL) |
| Mode: Fundamental |
| Frequency Tolerance (@25°C), 40 ppm |
| Frequency Tolerance df/dfo (0° – 70°C), 40 ppm |
| Load Capacitance: 20 pF |
| ESR: 50 Ω |
| C1(Internal Series Capacitance), 15 mpF |

This crystal is a common variety and is specified as a parallel resonant.

### Burst Flag Decoding

In order to encode to either NTSC or PAL compatibility, the MC13077 must first determine which is the intended standard. The MC13077 accomplishes this with an internal decode using the sync input and the output of the divide by 4 ring counter. Internally, the Sync separator circuitry provides an output that is sampled by the subcarrier signal from the ring counter. The result is an internal sync representative of externally input sync but synchronized to the internal subcarrier signal. This signal provides a reset for an internal 9–bit counter that provides divisions of the subcarrier signal from the ring counter at powers of 2 (i.e. $2^1$, $2^2$, $2^3$,...$2^9$ = 512). The eighth bit of the counter gives the output, $f_{SC} \div 256$. The decision to provide burst gate timing for PAL or NTSC is based upon the state of this output after one period of the horizontal sync. Figure 5 shows the relationship between the clock and the eighth bit of the counter.

Triggering of the burst PAL flip–flop due to equalizing pulses is also inhibited by the decode circuitry. This is done by counting out beyond a half line interval before generating burst flag.

If the MC13077 is encoding 525/60 component video to NTSC and the MC13077 is generating the burst flag, the start of burst will occur 18 counts after the leading edge of sync has been sampled, and will continue until nine cycles of burst have occurred. Since the reset pulse of the 9–bit counter has a resolution of $1.0/f_{SC}$, this implies that the start of burst will occur 5.17 ± 0.1397 µs after the leading edge of sync and also that the start (and end) of burst may differ by as much as 279.4 ns from line–to–line. If the MC13077 is encoding 625/50 to PAL, the subcarrier frequency will be 4.43361875 MHz and that implies a resolution of 225.5 ns for the burst position. For PAL encoding, 24 counts of the subcarrier are necessary before burst is initiated. So ten cycles of subcarrier will occur 5.53 ± 0.1128 µs after the leading edge of sync. After the timing of the burst gate is selected, the burst gate envelope is added to the color difference components.

Another alternative to the internal determination of burst flag is the external input of burst flag. This allows the user to externally define the exact timing and duration of color burst. If external burst flag is available, it can be inserted at Pin 18. The threshold level is nominally $V_{CC}/2$ and the input should not exceed $V_{CC}$. Burst will begin when the leading edge of the burst flag input exceeds $V_{CC}/2$ and will stop when it falls below $V_{CC}/2$. If it is desired to disable the burst flag, Pin 18 can be pulled low. It is also possible to insert burst flag with the R–Y and B–Y components. This is done at the clamp pins with the respective color difference inputs with the internal burst flag generation disabled (Pin 18 grounded).

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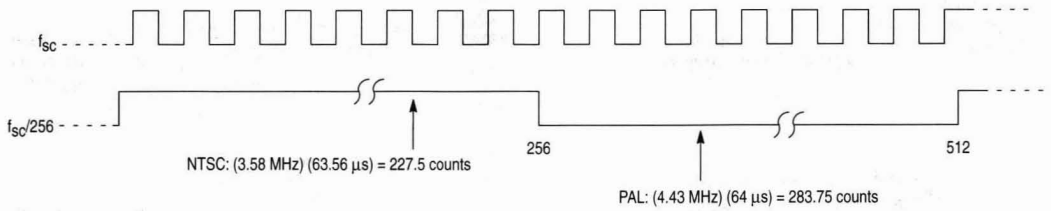
**Figure 5. Relationship Showing the Counts of a 3.58 MHz Clock versus a 4.43 MHz Clock at the End of a Horizontal Period**




### Chroma Band Limiting and Luma Delay

Once the color difference and burst flag envelopes have been modulated, the two components are internally summed and applied to an output buffer that will drive the external bandpass circuitry before entering the chip again at Pin 20. The sum of the color difference modulators produces an output that is high in harmonic content. For this reason, and to reduce the possibility of cross color, a chroma bandpass transformer is used to band–limit the chroma. Suggested bandpass filters and specifications for NTSC and PAL are shown in Figure 7a and 7b. For each of these filters, approximately 300 ns of group delay is experienced by the filtered chroma. There is also an internal delay on the order of 100 ns due to internal filtering that must be considered. Thus a 400 ns luma delay line is used to equalize the timing of the luma and the chroma. Suitable 400 ns delay lines are the TOKO H321LNP–1436PBAB and the TDK DL122401D–1533. The delay of the luma channel is inserted between Pins 10 and 6. Pin 10 is the buffered output of the luma from the RGB matrix. This output is capable of driving the external passive delay line with no external gain or buffering required.

**Figure 7a. Group Delay and Magnitude Response of the TOKO Bandpass Filter Intended for NTSC Applications**

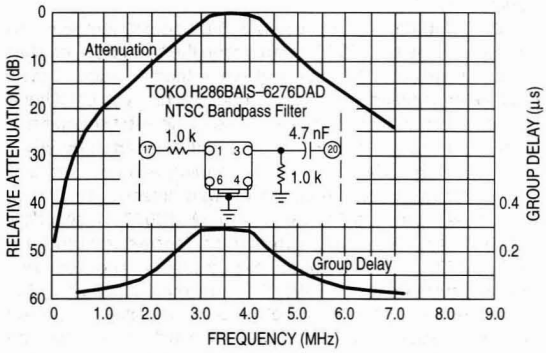
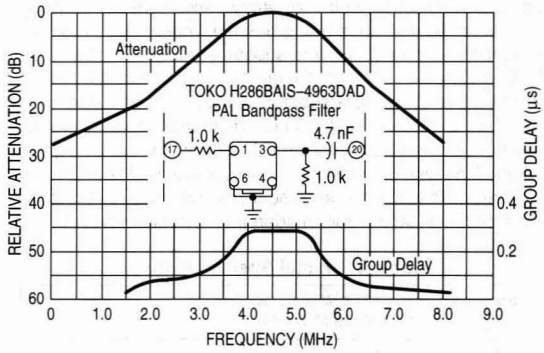



**Figure 7b. Group Delay and Magnitude Response of the TOKO Bandpass Filter Intended for PAL Applications**




**Characteristics of TOKO Bandpass Filter (H286BAIS – 6276DAD)**

| **Frequency** (MHz) | **Attenuation** (dB) | **Group Delay** (µs) |
|---|---|---|
| 2.0 | 8.0 (min) | 0.12 |
| 2.8 | 3.0 ± 3.0 | 0.25 |
| 3.58 | Ins. Loss 3.5 (max) | 0.290 ± 0.030 |
| 4.3 | 3.0 ± 3.0 | 0.24 |
| 6.2 | 15 (min) | 0.05 |

**Characteristics of TOKO Bandpass Filter (H286BAIS – 4963DAD)**

| **Frequency** (MHz) | **Attenuation** (dB) | **Group Delay** (µs) |
|---|---|---|
| 2.50 | 10 (min) | 0.075 |
| 3.73 | 3.0 ± 3.0 | 0.24 |
| 4.43 | Ins Loss 2.0 (max) | 0.295 ± 0.035 |
| 5.13 | 3.0 ± 3.0 | 0.24 |
| 6.50 | 12 (min) | 0.05 |

### Chroma Encoding

Modulation of the color difference components is performed by two double–balanced mixers that are driven from quadrature signals provided by an internal ring counter. The quadrature signals are derived from a ring counter that is driven by the 4x oscillator, and which makes highly accurate quadrature angles possible.

If PAL encoding is selected, negative burst flag envelope is provided to both B–Y and R–Y components equally, then the R–Y envelope phase is switched positive and negative from line–to–line to provide the PAL alternating burst phase characteristic. An internal flip–flop that provides the internal $f_H/2$ switching is enabled by opening the connection at Pin 19. If enabled, the pin will exhibit the internally generated half line frequency squarewave. If it is desired to reverse the sense of the PAL swinging burst, it can be done at this pin by pulling Pin 19 low when the squarewave is high. The component envelopes with the proper PAL burst phase are then modulated to produce the composite chroma.

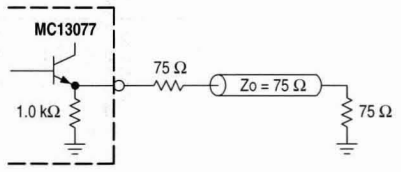
If the MC13077 is encoding to NTSC, only the B–Y color difference component is provided a negative burst flag. This envelope when modulated results in the characteristic –180° phase difference between the color burst and the subcarrier for the B–Y component. Pin 19 should be grounded for NTSC operation to disable the PAL flip–flop.

### Video Outputs

After being filtered, the composite chroma is recombined with the composite luma information for the Composite Video output. The composite chroma and composite luma components are also kept separate and buffered for the chroma S–Video and luma S–Video outputs. The video outputs are provided with low impedance emitter–follower stages and, therefore, require an external 75 Ω impedance determining series resistor (see Figure 7). The outputs are designed to drive a 75 Ω load through the external 75 Ω series resistor.

The Composite Video output will provide 1.23 Vpp of video (sync tip–to–peak chroma) for 100% saturated video at the 75 Ω load. Luma S–Video will be 1.0 Vpp (sync tip–to–peak white) at the 75 Ω load and the Chroma S–Video output will provide 885 mVpp at the 75 Ω load.

**Figure 7. Composite S–Luma and S–Chroma Video Outputs**




## APPLICATIONS INFORMATION

Figures 8 through 13 are application examples showing the versatility of the MC13077.

**Figure 8. Standard Encoder Application with RGB Inputs and Phase–Locked Subcarrier**

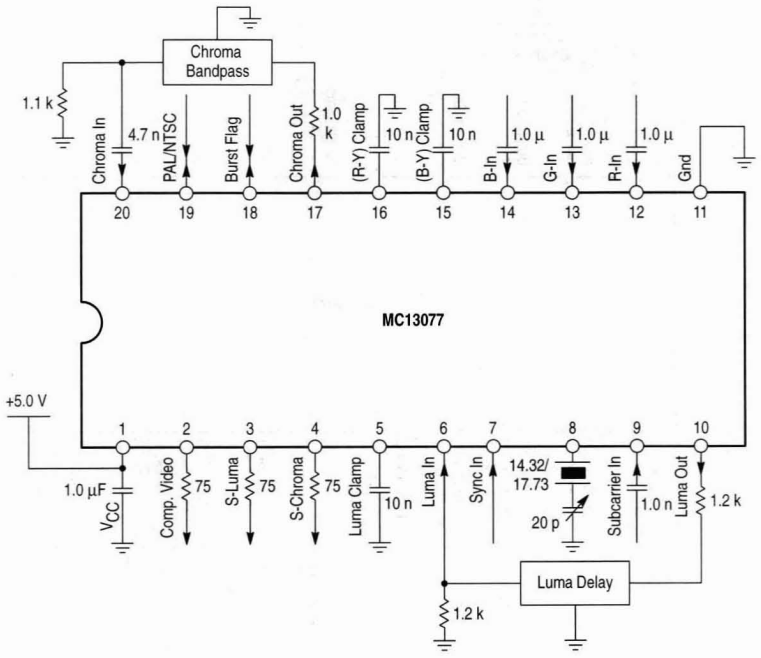



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**Figure 9. Encoder with RGB Inputs and Unlocked Subcarrier**

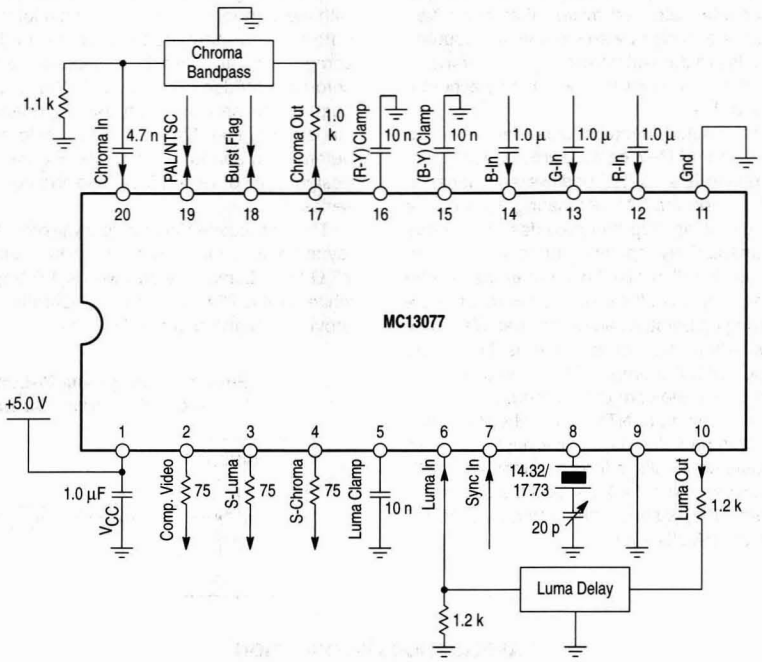


**Figure 10. Encoder with RGB Inputs and 4x Subcarrier Drive**

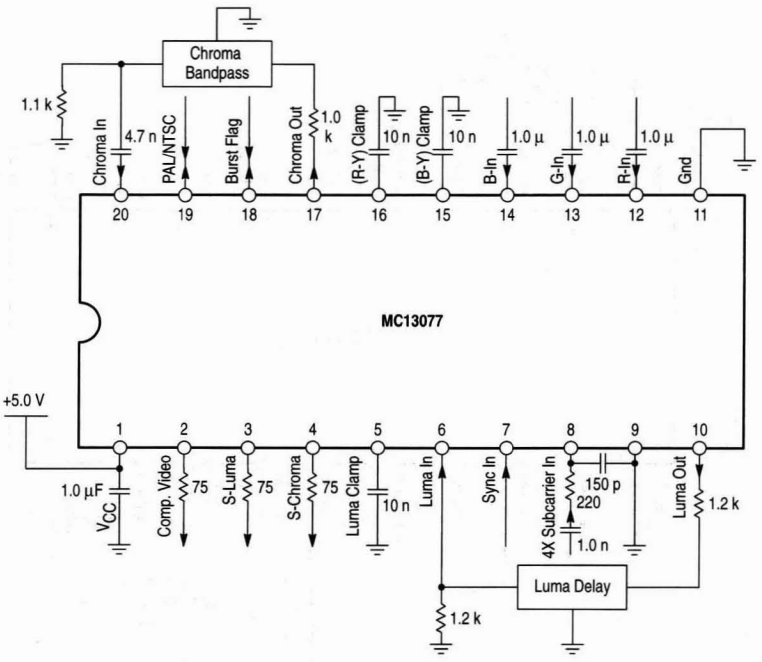

**Figure 11. Encoder with Luma and Color Difference Inputs Using Phase–Locked Subcarrier**

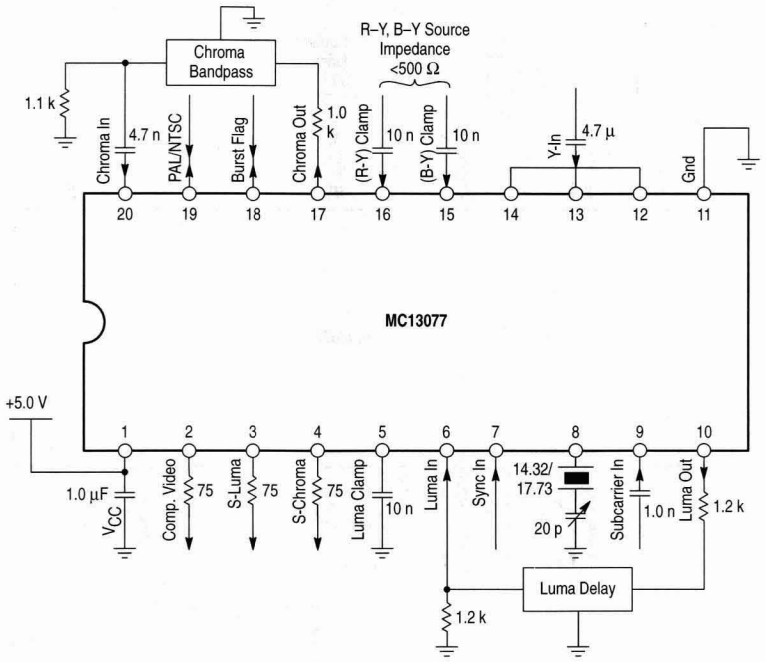


**Figure 12. Encoder with Composite Luma and Color Difference Inputs Using Phase–Locked Subcarrier**

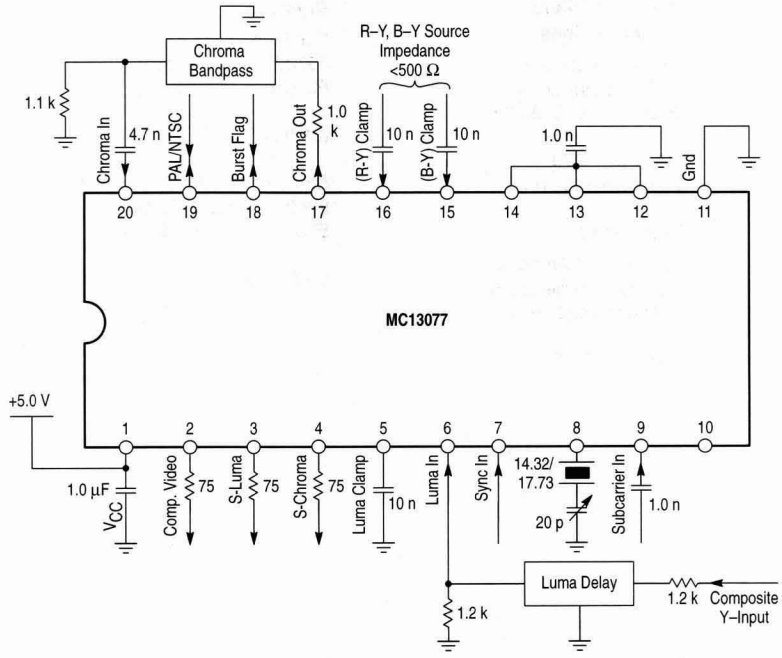


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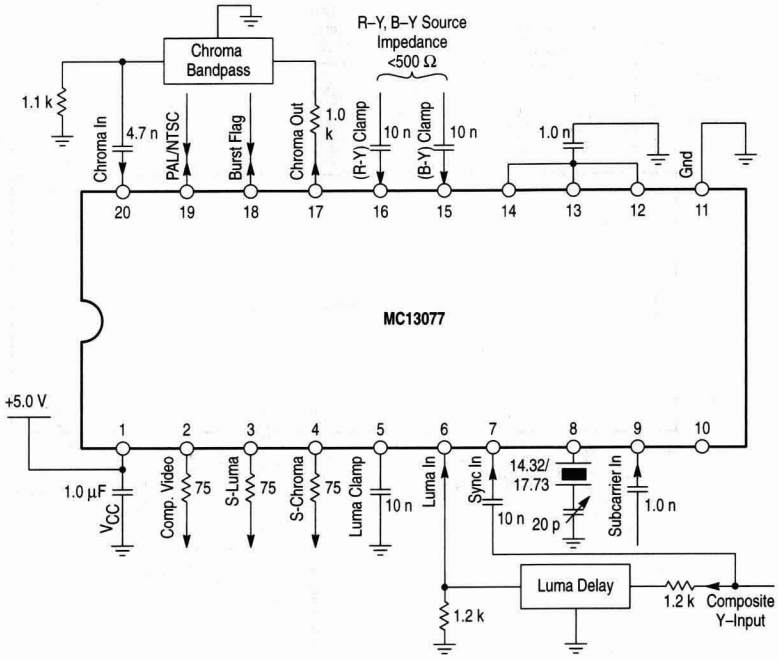
**Figure 13. Encoder with Composite Luma and Color Difference Inputs Using the Sync Separator and Having Phase–Locked Subcarrier**




## Recommended Vendors

**Bandpass Filters and Delay Lines**

TOKO America Inc.
1250 Feehanville Drive
Mt. Prospect, IL 60056

(708) 297–0070
(708) 699–7864 (fax)

**Delay Lines**

TDK Corp. of America
1600 Feehanville Drive
Mt. Prospect, IL 60056

(708) 803–6100

**Crystals**

Fox Electronics
5570 Enterprise Pkwy
Ft. Myers, FL 33905

(813) 693–0099

Standard Crystal Corporation
9940 E. Baldwin Place
El Monte, CA 91731

(818) 443–2121

MOTOROLA

# MC13081X

*Advance Information*

## Multimode Color Monitor Horizontal, Vertical, and Video Combination Processor

**MULTIMODE COLOR MONITOR PROCESSOR**

**SEMICONDUCTOR TECHNICAL DATA**

The MC13081X includes all the signal processing functions for a scan frequency agile and multiple sync system analog RGB monitor and includes the following functions:

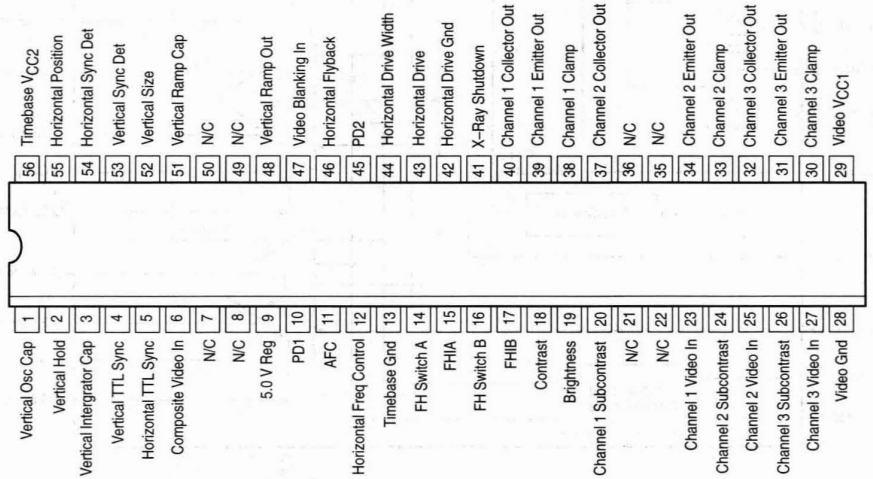
- Automatic Horizontal Frequency Tracking of All Commonly Used Personal Computers, Continuously Adaptable from 30 kHz to 64 kHz
- Sync–on–Green Detection
- Vertical Timebase Operates from 45 to 100 Hz
- Vertical and Horizontal Sync Polarity Detection with Outputs for Mode Switching
- Video Pre–Amplifiers Typical Rise/Fall Time of 5.0 ns at 3.0 Vpp Output Voltage Swing
- Overall Contrast Control and Independent RGB Gain Controls

**B SUFFIX**
PLASTIC SDIP PACKAGE
CASE 859

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13081XB | $T_A$ = 0° to +70°C | Plastic SDIP |

**PIN CONNECTIONS**




(Top View)

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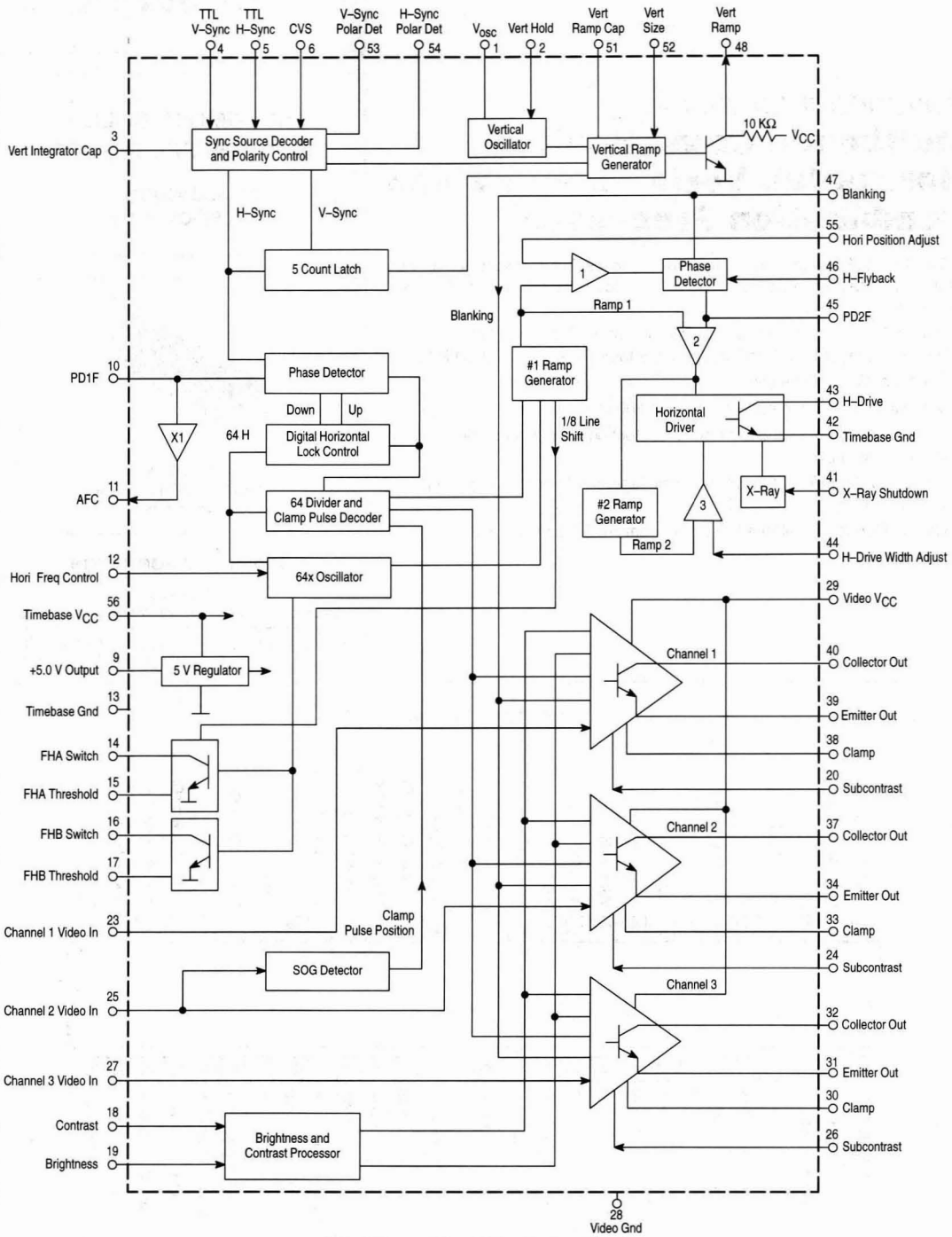
**Figure 1. Block Diagram**




This device contains 1074 active transistors.

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage<br>Video Section $V_{CC1}$<br>Timebase Section $V_{CC2}$ | <br>29<br>56 | <br>–0.5, +10<br>–0.5, +10 | Vdc |
| Brightness, Contrast, Horizontal Flyback Input, Frequency Switch when Off | 19, 18, 46, 14, 16 | 0 to $V_{CC}$ | Vdc |
| X–Ray Shutdown | 41 | –0.5, +0.9 | Vdc |
| Subcontrast RGB Controls | 20, 24, 26 | 0 to +2.0 | Vdc |
| Horizontal Drive Width, Horizontal Position | 44, 55 | 0 to +5.0 | Vdc |
| Voltage on Horizontal Drive when Off, Vertical TTL Sync Input, Horizontal TTL Sync Input, Composite Video Sync Input, Video Amplifier Output Collectors | 43, 4, 5, 6, 32, 37, 40 | –0.5 to $V_{CC}$ + 0.5 | Vdc |
| Current into Horizontal Drive when On | 43 | 100 | mA |
| Current into Frequency Switch when On | 14, 16 | 30 | mA |
| Video Amplifier Inputs | 23, 25, 27 | –0.5, + 5.0 | Vdc |
| Video Amplifier Output Current (Total for the Three Channels) | 40, 39, 37, 34, 32, 31 | 120 | mA |
| Storage Temperature | – | –65 to +150 | °C |
| Junction Temperature | – | +150 | °C |

**NOTE:** ESD data available upon request.

**RECOMMENDED OPERATING CONDITIONS**

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage<br>Video Section $V_{CC1}$<br>Timebase Section $V_{CC2}$ | <br>29<br>56 | <br>7.6<br>7.6 | <br>8.0<br>8.0 | <br>8.4<br>8.4 | Vdc |
| Power Supply Voltage Difference, $V_{CC2} - V_{CC1}$ | – | –0.3 | 0 | 0.8 | Vdc |
| Internal 5.0 V Regulator Output Current | 9 | –20 | – | 0 | mA |
| Contrast Control | 18 | 0 | – | 5.0 | Vdc |
| Brightness Control | 19 | 0 | – | 5.0 | Vdc |
| Subcontrast Control | 20, 24, 26 | 0 | – | 2.0 | Vdc |
| Horizontal Drive Width Adjust | 44 | 0 | – | 5.0 | Vdc |
| Horizontal Position Adjust | 55 | 1.0 | – | 4.0 | Vdc |
| Horizontal Flyback Signal Amplitude | 46 | 0.7 | 5.0 | 8.0 | V |
| Horizontal Flyback Signal DC Input Voltage Level | 46 | –0.2 | 0 | – | Vdc |
| Voltage on Horizontal Drive Collector when "Off" | 43 | 0 | – | $V_{CC}$ | V |
| Current into Horizontal Drive Collector when "On" | 43 | 0 | – | 40 | mA |
| Voltage on Horizontal Drive Emitter W.R.T. Circuit Ground | 42 | –0.3 | 0 | 2.0 | Vdc |
| Blanking Input Signal Amplitude | 47 | 1.5 | – | 4.0 | V |
| Voltage on FH Switches when "Off" | 14, 16 | 0 | – | 8.0 | Vdc |
| Current into each FH Switch when "On" | 14, 16 | 0 | – | 20 | mA |
| X–Ray Shutdown | 41 | 0 | – | 0.7 | Vdc |
| Composite Video Sync Input | 6 | 1.0 | – | 2.0 | Vpp |
| Vertical Sync Frequency | – | 45 | – | 100 | Hz |
| Horizontal Sync Frequency | – | 30 | – | 64 | kHz |
| Vertical Sync Pulse Width | – | – | 70 | – | µs |
| Horizontal Sync Pulse Width | – | – | 1.0 | – | µs |

**RECOMMENDED OPERATING CONDITIONS (continued)**

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Video Signal Amplitude (with 75 Ω Termination) | 23, 25, 27 | 0.5 | 0.7 | 1.2 | Vpp |
| Voltage on Video Amplifier Collector | 32, 37, 40 | 4.5 | – | $V_{CC}$ | Vdc |
| Current Through Video Collector–Emitter | 40, 39, 37<br>34, 32, 31 | 0 | – | 40 | mA |
| Vertical Hold Set Resistance, R9 + VR2 (Figure 2) | 2 | – | 10 | – | kΩ |
| Vertical Size Set Resistance, R10 + VR3 (Figure 2) | 52 | – | 220 | – | kΩ |
| Vertical Linearity Set Resistance, R12 + VR4 (Figure 2) | 51 | – | 1000 | – | kΩ |
| Operating Ambient Temperature | – | 0 | 25 | 70 | °C |
| FH Switches Set Resistance | 15, 17 | See Application Section 5 | | | – |
| Vertical TTL Sync Input | 4 | TTL Voltage Level | | | Vdc |
| Horizontal TTL Sync Input | 5 | TTL Voltage Level | | | Vdc |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, $V_{CC}$ = 8.0 Vdc)

| Characteristic | Condition | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **POWER SUPPLIES** | | | | | | |
| Supply Current<br>Total Consumption | – | 29, 56 | 70 | 85 | 110 | mA |
| 5.0 V Regulator | | 9 | | | | |
| Output Voltage | Load Current ($I_B$) = 0 mA | | 4.75 | 5.0 | 5.25 | Vdc |
| Line Regulation | 7.6 V < $V_{CC}$ < 8.4 V, $I_B$ = 0 mA | | – | 25 | – | mV |
| Load Regulation | –10 mA < $I_B$ < 0 mA | | – | 100 | – | mV |
| Temperature Coefficient | | | – | –0.3 | – | mV/°C |
| Thermal Resistance, Junction–to–Ambient | – | – | – | 59 | – | °C/W |
| **HORIZONTAL PROCESSING** | | | | | | |
| Horizontal Oscillator Frequency Range | – | 43 | 30 | – | 64 | kHz |
| Horizontal Oscillator Free Running Frequency @ I12 = 240 µA | Sink 240 µA from Pin 12 with Resistor R5 Opened | 43 | 29 | 31 | 33 | kHz |
| Horizontal Sync Detector Output/+$V_E$ Sync | – | 54 | – | 0 | – | Vdc |
| Horizontal Sync Detector Output/–$V_E$ Sync | – | 54 | – | 3.6 | – | Vdc |
| Horizontal Sync Input | – | 5 | | | | |
| Input Impedance | | | – | 22 | 0 | kΩ |
| Input Level – Low | | | 0 | – | 0.8 | Vdc |
| Input Level – High | | | 2.4 | – | 5.0 | Vdc |
| Composite Video Sync Input | – | 6 | | | | |
| Input Impedance | | | – | 1.0 | – | kΩ |
| Internal Bias Level | | | – | 1.55 | – | Vdc |
| Minimum Input Amplitude | | | 0.1 | – | – | Vpp |
| Short Term Horizontal Pull–In Range | Time < 5.0 ms | – | – | ±5.0 | – | %FH |
| Long Term Horizontal Pull–In Range | Time > 500 ms | – | 30 | – | 64 | kHz |
| Horizontal Frequency Control (Current Transfer Constant) | Current Flowing Out of Pin 12 | 12 | 115 | 122 | 129 | Hz/µA |
| Horizontal Free Running Frequency Change versus Temperature | Pin 11 is Opened | – | – | 300 | – | ppm/°C |
| FH Switch Threshold Pins | – | 15, 17 | | | | |
| Output Current | | | – | I12/2 | – | µA |
| Threshold | | | – | 5.0 | – | V |
| Hysteresis | | | 0 | – | 200 | mV |
| FH Switch Voltage when "On" | I = 10 mA | 14, 16 | – | – | 200 | mVdc |

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**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC}$ = 8.0 Vdc)

| Characteristic | Condition | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **HORIZONTAL DRIVE** | | | | | | |
| Horizontal Position Adjust | 0 < V55 < 5.0 V, | 55 | | | | |
| Range | FH = 30 k – 56 kHz | | – | 10 | – | % |
| Input Impedance | See Application Section 7 | | – | 31 | – | kΩ |
| Horizontal Drive Width Adjust | FH = 35 kHz, 0 < V44 < 5.0 V | 44 | | | | |
| Range | | | 2:1 | – | 1:2 | % |
| Input Impedance | | | – | 30 | – | kΩ |
| Horizontal Flyback | See Application Section 4 | 46 | | | | |
| Threshold | Input Signal Should Not Fall | | – | 0.7 | – | V |
| Input Amplitude | Below –0.2 V | | 0 | – | 8.0 | V |
| Input Impedance | | | – | 10 | – | kΩ |
| Horizontal Drive | | 43 | | | | |
| Output Low | $I_{sink}$ = 40 mA | | 0 | – | 0.3 | Vdc |
| Output High | V43 = $V_{CC}$ | | – | – | 100 | µA |
| Time Delay from Flyback to Video Output Blanking | See Application Section 7 | – | – | 250 | – | ns |
| Time Delay from Blanking to Video Output Blanking | See Application Section 7 | – | – | 400 | – | ns |
| X–Ray Shutdown Activate Voltage | See Application Section 11 | 41 | 0.4 | 0.58 | 0.7 | Vdc |
| Temperature Coefficient of X–Ray Threshold Voltage | – | 41 | – | –2.3 | – | mV/°C |
| Horizontal Jitter | 30 kHz < FH < 56 kHz | 43 | – | 3.0 | – | ns |
| **VERTICAL PROCESSING** | | | | | | |
| Vertical Ramp Frequency | – | 48 | 45 | – | 100 | Hz |
| Vertical Ramp | FV = 50 Hz, | 48 | | | | |
| Amplitude | R12 + VR4 = 820 kΩ | | – | 3.0 | – | Vpp |
| Minimum Peak | R10 + VR3 =120 kΩ, | | – | 1.9 | – | V |
| Maximum Peak | C6 = C7 = 1.0 µF | | – | 3.4 | – | V |
| Output Current | | | – | 2.0 | – | mA |
| Non–Linearity | | | – | 0.45 | 1.0 | % |
| Vertical Ramp Free Running Temperature Drift | FV = 50 Hz | 48 | – | 0.01 | – | Hz/°C |
| Vertical Ramp Free Running Drift with $V_{CC}$ | FV = 50 Hz | 48 | – | 0.5 | – | Hz/V |
| Vertical Ramp Discharge Rate (Retrace) | FV = 50 Hz | 48 | – | 9.5 | – | V/ms |
| Vertical Sync Detector Output/+$V_E$ Sync | | 53 | – | 0 | – | Vdc |
| Vertical Sync Detector Output/–$V_E$ Sync | | 53 | – | 3.6 | – | Vdc |
| Vertical Sync Input | – | 4 | | | | |
| Input Impedance | | | – | 22 | – | kΩ |
| Input Level – Low | | | 0 | – | 0.8 | Vdc |
| Input Level – High | | | 2.4 | – | 5.0 | Vdc |
| **VIDEO AMPLIFIERS** | | | | | | |
| Input Impedance | – | 23, 25,27 | 100 | – | – | kΩ |
| Internal DC Bias Voltage | | | – | 2.4 | – | Vdc |
| Output Signal Amplitude | $V_{in}$ = 0.7 Vpp, V18 = 5.0 V | 39, 34, 31 | – | 3.6 | – | Vpp |
| Voltage Gain | V20 = V24 = V26 = 0 V | | – | 5.1 | – | V/V |
| Contrast Control | V18 = 0 to 5.0 V; V20, 24, 26 = 0 V | 18 | – | 20 | – | dB |
| Subcontrast Control | V20, 24, 26 = 2.0 to 0 V; V18 = 5.0 V | 20, 24, 26 | 1:2.5 | – | – | – |
| Brightness Control | V19 = 0 to 5.0 V, Measure Pin 39, 34, 31 DC Level | 19 | – | ±0.5 | – | Vdc |

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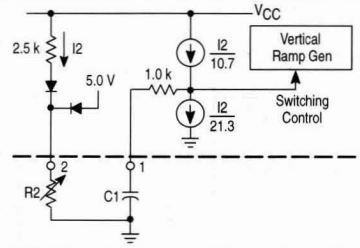
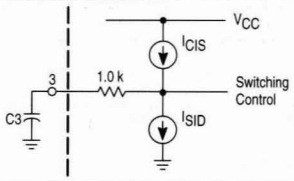
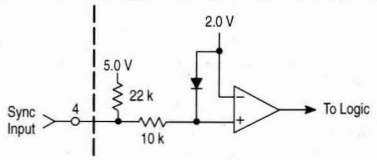
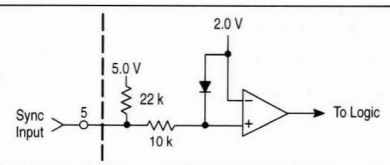
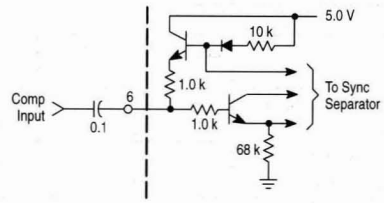
**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC}$ = 8.0 Vdc)

| Characteristic | Condition | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **VIDEO AMPLIFIERS** | | | | | | |
| Emitter DC Level | | 39, 34, 31 | | | | Vdc |
| Minimum Brightness | V19 = 0 V | | – | 1.0 | – | |
| Nominal Brightness | V19 = 2.5 V | | 1.25 | 1.5 | 1.75 | |
| Maximum Brightness | V19 = 5.0 V | | – | 2.0 | – | |
| Crosstalk, Amplifier to Amplifier | Frequency = 10 MHz | 39, 34, 31 | – | 34 | – | dB |
| Output Rise Time | $V_{in}$ = 0.7 Vpp; $V_{out}$ = 3.0 Vpp | 39, 34, 31 | – | 5.0 | – | ns |
| Output Fall Time | | | – | 5.0 | – | |

**PIN FUNCTION DESCRIPTION**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 1 | Vertical Oscillator Capacitor |  | This capacitor should be 100 nF film type to give good temperature stability. |
| 2 | Vertical Hold Control | | The potentiometer at Pin 2 adjusts the free running frequency of the oscillator. It should normally be set for about 55 Hz with no vertical signal input such that it will lock to 60 Hz. |
| 3 | Vertical Integrator Capacitor |  | The capacitor on this pin integrates the sync pulses with a long time constant. C3 is typically 0.01 µF. |
| 4 | Vertical TTL Sync |  | Vertical TTL Sync input. The input threshold voltage at this pin is 2.0 V. |
| 5 | Horizontal TTL Sync |  | Composite or Horizontal TTL Sync input. The input threshold voltage at this pin is 2.0 V. |
| 6 | Composite Video Input |  | This pin requires a coupling of min 100 nF. The composite sync input should consist of $-V_E$ sync signal only with amplitude > 500 mVpp.<br><br>The source impedance of the sync signal should be <1.0 kΩ.<br><br>Sync information at Pin 5 will override this pin, but signals at Pin 4 will not.<br><br>Minimum pulse width is 2.0 µs. |
| 7, 8 | N/C | | These two pins are internally connected to each other, and nothing else. |

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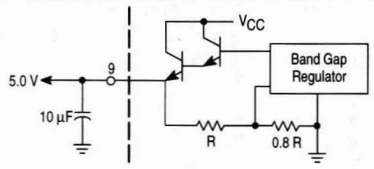
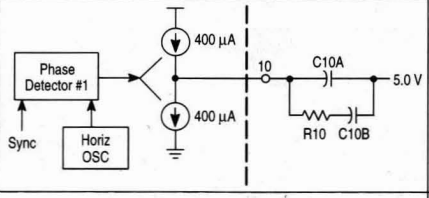
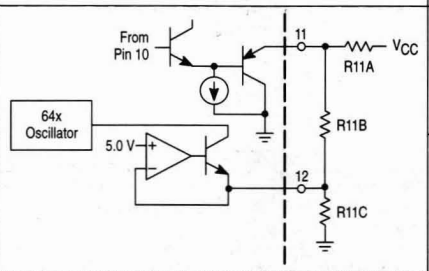
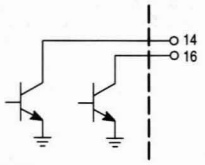
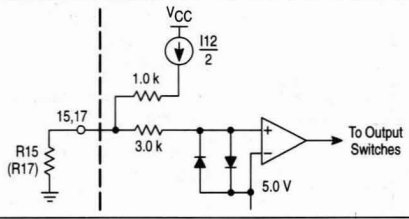
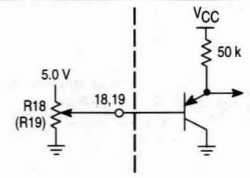
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 9 | 5.0 V Regulator Output |  | 5.0 V (±5%) regulator. Minimum 10 µF capacitor is required for noise filtering and compensation. Up to 20 mA can be supplied to external circuitry. It can source but not sink current. Output impedance is ≈ 10 Ω.<br>This 5.0 V regulator is recommended for use as a reference only. |
| 10 | Phase Detector 1 Filter |  | External components at this pin will determine the PLL gain and phase characteristics. The capacitors should be non–polarized.<br>The voltage at this pin nominally ranges from 1.5 V to 5.0 V with corresponding horizontal frequency from 25 kHz to 68 kHz. |
| 11 | Automatic Frequency Control |  | Pin 11 is a buffered equivalent of Pin 10, and ranges from a minimum of 1.5 V at horizontal high frequency to near 5.0 V at low frequency. Pin 11 can sink a maximum of 1.0 mA, but cannot source current. |
| 12 | Horizontal Frequency Range | | The current out of Pin 12 determines the horizontal frequency by a current transfer constant of ≈ 122 Hz/µA.<br>Pin 12 is internally maintained at 5.0 V. |
| 13 | Timebase Ground | | Ground for the timebase section. Connect to a clean, low impedance ground. |
| 14, 16 | FH Switch A, B |  | Pin 14 (Switch A), and Pin 16 (Switch B) are open collector NPN switches to ground. Each switch is "on" when the horizontal frequency is higher than the set points set by resistors at Pins 15 and 17, respectively.<br>Maximum voltage is 8.0 V, and maximum sink current is 20 mA. |
| 15, 17 | FH Switch A, B Threshold Setting |  | Pin 15 and Pin 17 are current mirror at 1/2 of Pin 12 current. External resistors at these pins set the horizontal frequency at which Pins 14 and 16 will switch, respectively. The threshold voltage is 5.0 V. |
| 18 | Contrast Control |  | The input control range is from 0 to 5.0 V. An increase of voltage increases contrast. |
| 19 | Brightness Control | | The input control range is from 0 to 5.0 V. An increase of voltage increases brightness. |

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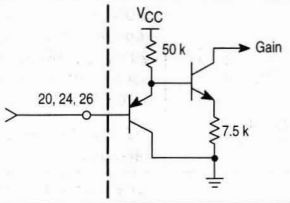
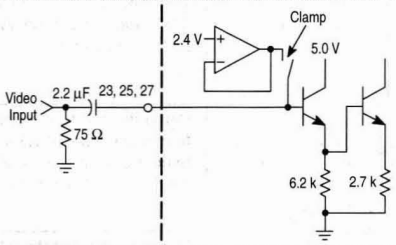
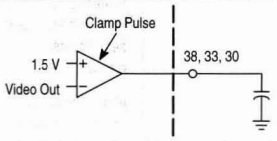
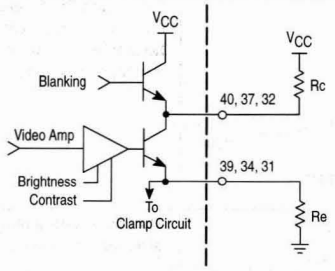
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 20<br>24<br>26 | Subcontrast Control<br>Channel 1<br>Channel 2<br>Channel 3 |  | Subcontrast controls the gain of each video channel. 0 V for maximum gain, and 2.0 V for minimum gain. |
| 21, 22 | N/C | | These two pins are internally connected to each other, and nothing else. |
| 23<br>25<br>27 | Video Inputs<br>Channel 1<br>Channel 2<br>Channel 3 |  | The input coupling capacitor is used for input clamp storage. The maximum source impedance is 100 Ω. Polarity of the input video signal is positive. Amplitude should be nominally 0.7 Vpp. |
| 28 | Video Ground | | Ground for the video section (video amplifiers, contrast and brightness controls, subcontrast, and video reference voltage).<br>Noise from the timebase section, and other digital circuits, should not be allowed to produce ground bounce at this pin. |
| 29 | Video $V_{CC1}$ | | Connected to a 8.0, V ±5%, dc supply. Decoupling is required at this pin. |
| 38<br>33<br>30 | Video Clamp<br>Channel 1<br>Channel 2<br>Channel 3 |  | Normally a 100 nF capacitor is connected to each of these pins. |
| 39<br>34<br>31<br><br><br>40<br>37<br>32 | Video Emitter Output<br>Channel 1<br>Channel 2<br>Channel 3<br>Video Collector Output<br>Channel 1<br>Channel 2<br>Channel 3 |  | Pins 39, 34, and 31 are the emitter outputs of the three video amplifier, and have an internal 33 Ω resistor.<br>The emitter dc voltage is controlled by the brightness control.<br>The current through each collector and emitter should not exceed 40 mA. |
| 35, 36 | N/C | | These two pins are internally connected to each other, and nothing else. |

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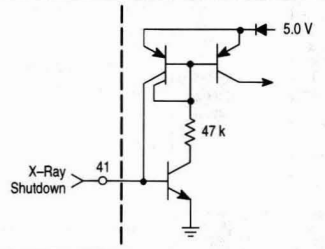
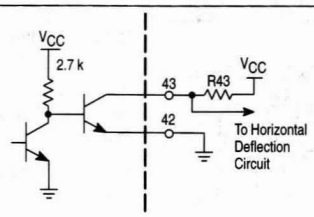
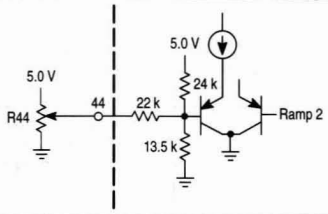
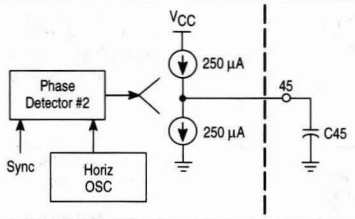
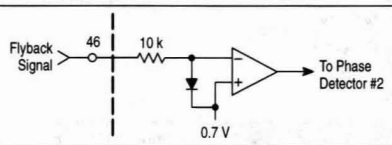
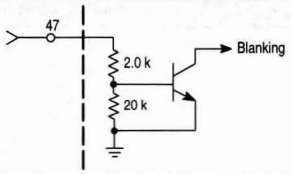
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 41 | X–Ray Shutdown |  | If the voltage at this pin is > 0.58 V, the horizontal driver device (Pins 42 and 43) will be "on" until power is removed, or the voltage on this pin is taken below 0.4 V. |
| 42 | Horizontal Drive Ground |  | This emitter pin must be connected externally to a low impedance ground.<br>Pin 43 is an open collector pin and normally is pulled up by a resistor to $V_{CC}$.<br>Maximum current through Pins 42 and 43 must be less than 40 mA. |
| 43 | Horizontal Drive | | |
| 44 | Horizontal Drive Width |  | Varying the voltage at this pin will change the horizontal drive duty cycle.<br>As the voltage of this pin is increased, the "on" time at Pin 43 is decreased.<br>Input impedance is ≈ 30 kΩ. |
| 45 | Secondary Phase Detector Filter |  | Typically a 10 to 100 nF decoupling capacitor is connected to this pin. |
| 46 | Horizontal Flyback |  | The flyback signal should be a $+V_E$ pulse of peak voltage 8.0 V. The internal switching voltage is 0.7 V and it controls the secondary PLL<br>Input impedance is ≈ 10 kΩ |
| 47 | Video Blanking Input |  | The video blanking signal should be positive pulse in the range of 1.5 to 4.0 V. |

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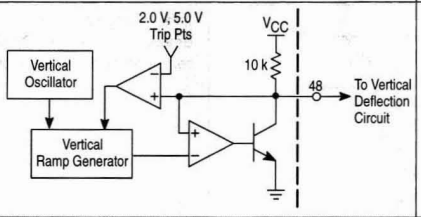
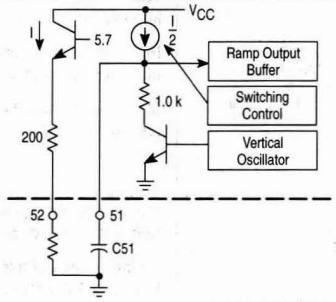
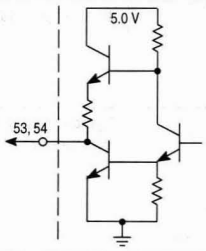
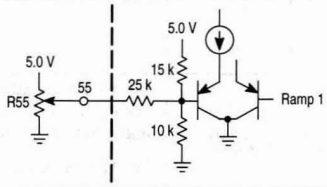
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 48 | Vertical Ramp Output |  | This ramp signal drives the external vertical output devices.<br>Voltage ramps from 2.0 V to less than 5.0 V, depending on frequency and components at Pins 51 and 52.<br>Loading on this pin must be > 30 kΩ to avoid distorting or clipping the ramp. |
| 49, 50 | N/C | | These two pins are internally connected to each other, and nothing else. |
| 51 | Vertical Ramp Capacitor |  | The slope of the output ramp is determined by the components at Pins 51 and 52.<br>The resistor at Pin 52 sets the charging current of the capacitor, and therfore the vertical height of the picture.<br>The linearity of the ramp can be modified by external feedback. |
| 52 | Vertical Size Control | | |
| 53 | Vertical Sync Polarity Detector |  | The output goes low when the vertical sync input polarity is positive. It goes high when the vertical sync input polarity is negative. |
| 54 | Horizontal Sync Polarity Detector | | The output goes low when the horizontal sync input polarity is positive. It goes high when the horizontal sync input polarity is negative. |
| 55 | Horizontal Position Control |  | Varying the voltage at this pin will change the horizontal position of the picture.<br>Input impedance is ≈ 31 kΩ. |
| 56 | Timebase $V_{CC2}$ | | Connected to a 8.0 V, ±5%, dc supply. Decoupling is required at this pin. |

9

## APPLICATION INFORMATION

The MC13081X is an integrated multisync color monitor processor. It combines horizontal/vertical deflection processing circuitry and video pre–amplifiers into a single device.

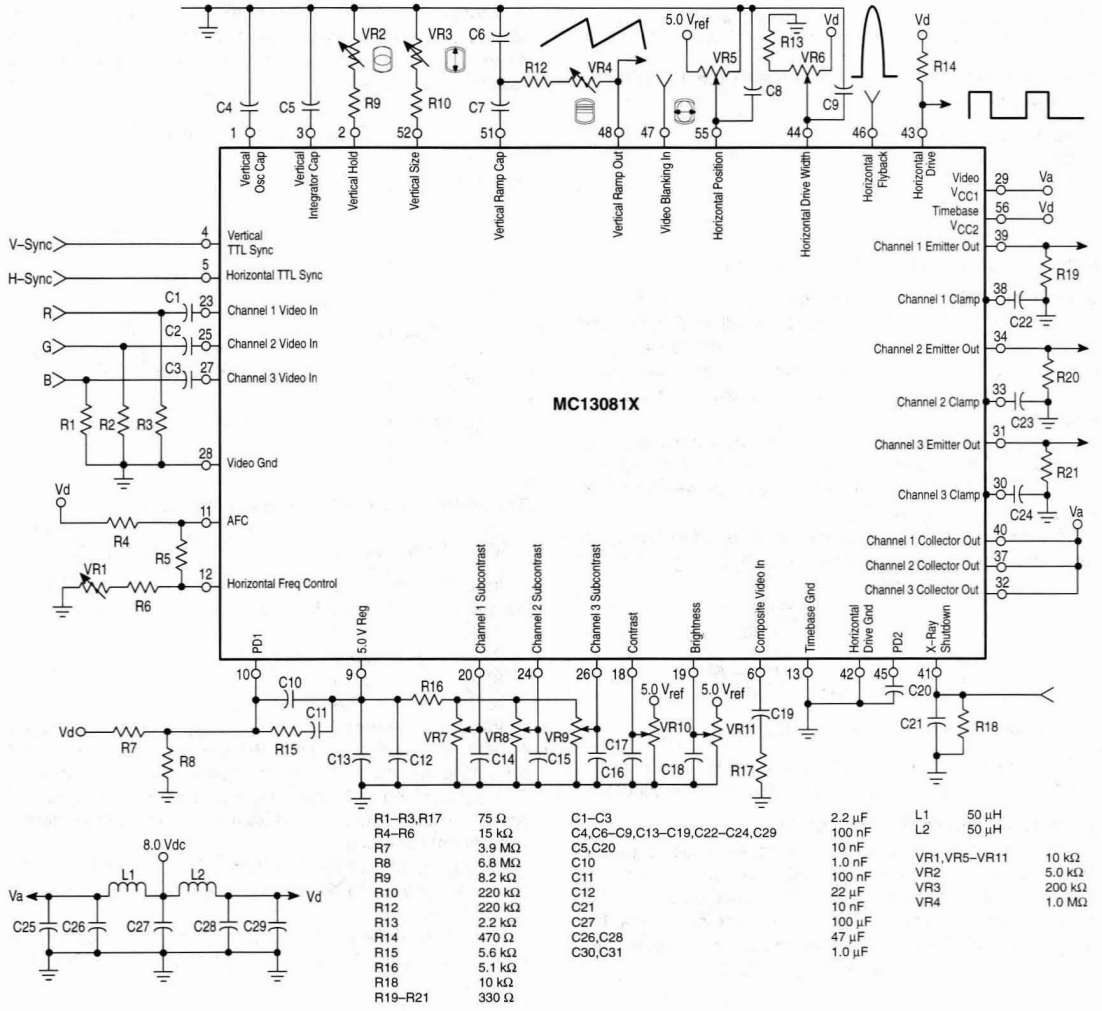
The overall timebase section consists of two parts: horizontal and vertical. The horizontal timebase can be operated from 30 kHz to 64 kHz, and can be driven from TTL separate sync, composite sync, or a composite video signal. There are two PLLs which ensure proper timing throughout the whole system. The first PLL provides line locking of the horizontal sync signal with the built–in oscillator, while the second one maintains fixed timing with the horizontal flyback signal such that a stable display can be achieved.

The vertical timebase section operates from 45 Hz to 100 Hz, and can receive various sync signals as the horizontal one does. This section consists of an oscillator and a ramp generator. Adjustments include linearity, ramp amplitude, and minimum free running frequency in the absence of sync signal.

The video section has three 70 MHz bandwidth pre–amplifiers. The outputs of these amplifiers are uncommitted collector/emitter facilitating cascode configuration with subsequent stages. Controls include brightness and contrast. In addition, the voltage gain of each amplifier can be adjusted individually which provides flexibility in adjusting color correctness. Blanking and clamping signals are provided to the amplifiers internally from the timebase section. Additionally, a blanking signal can also be supplied externally.

Separate power supply and ground pins are provided to the timebase and video section in order to minimize the cross interference between these two sections.

**Figure 2. Application Circuit**




| | | | | | |
|---|---|---|---|---|---|
| R1–R3,R17 | 75 Ω | C1–C3 | 2.2 µF | L1 | 50 µH |
| R4–R6 | 15 kΩ | C4,C6–C9,C13–C19,C22–C24,C29 | 100 nF | L2 | 50 µH |
| R7 | 3.9 MΩ | C5,C20 | 10 nF | | |
| R8 | 6.8 MΩ | C10 | 1.0 nF | VR1,VR5–VR11 | 10 kΩ |
| R9 | 8.2 kΩ | C11 | 100 nF | VR2 | 5.0 kΩ |
| R10 | 220 kΩ | C12 | 22 µF | VR3 | 200 kΩ |
| R12 | 220 kΩ | C21 | 10 nF | VR4 | 1.0 MΩ |
| R13 | 2.2 kΩ | C27 | 100 µF | | |
| R14 | 470 Ω | C26,C28 | 47 µF | | |
| R15 | 5.6 kΩ | C30,C31 | 1.0 µF | | |
| R16 | 5.1 kΩ | | | | |
| R18 | 10 kΩ | | | | |
| R19–R21 | 330 Ω | | | | |

The following describes a step–by–step procedure in using the MC13801 for a typical multisync color monitor chassis; component notations refer to Figure 2.

**1. Horizontal Frequency Range Resistor Network (Pins 11, 12)**

$F_{Hm}$ = Minimum Horizontal Frequency
$F_{Hx}$ = Maximum Horizontal Frequency
Oscillator Transfer Constant = 122 Hz/μA

$$R5 = \frac{6.35 \times 10^8}{F_{Hx} - F_{Hm}}$$

$$R6 = \frac{5}{\frac{F_{Hx}}{122 \times 10^6} - \frac{3.5}{R5}}$$

$$R4 \leq \frac{V_{CC} - 6.0}{1.5} \times R5 \text{ and } \frac{V_{CC} - 1.5}{R4} < 1.0 \text{ mA}$$

For most applications, R4 = R5 provides the required results.

**NOTE:** In order to compensate device/component tolerance, a potentiometer is recommended in series with R6, as VR1.

**2. Horizontal Frequency Range Phase Detector Filter Network (Pin 10)**

Typical values are:
C10 = 1.0 nF
C11 = 100 nF
R15 = 5.6 k
C11 ≥ 100 x C10

**NOTE:** C10 and C11 should have less than 1.0 μA leakage.

**3. Horizontal Free Running Frequency**

The voltage at Pin 10 will be buffered to Pin 11, and hence control the internal oscillator. In the absence of horizontal sync signal, the free running horizontal frequency will vary between preset minimum and maximum horizontal frequency values.

If an undetermined free running frequency value is not desired, a large impedance resistor can be used to pull Pin 10 to $V_{CC}$ or Gnd, and the free running frequency will be equal to $F_{Hm}$ or $F_{Hx}$, respectively.

The free running frequency can also be set to any value within the horizontal frequency range by using a voltage divider, as R7 and R8 indicate.

$$V11 = V_D \times \frac{R7}{R7 + R8}$$

$$I12 = \frac{V11}{R6 + VR1} - \frac{V11 - 5}{5}$$

$$\text{Free Running Frequency} = I12\ \mu A \times \frac{122\ Hz}{\mu A}$$

The above formula provides the ratio of R7 and R8. The values chosen should be similar to those shown in Figure 2.

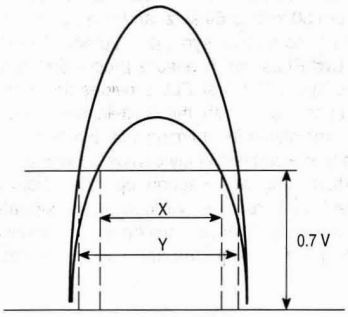
**4. Horizontal Flyback Input (Pin 46)**

The horizontal flyback signal not only provides proper timing reference for the horizontal drive output, but also supplies the necessary blanking for the video outputs.

There are two precautions for the flyback input. First, the signal should have a zero volt reference, and second, the peak value should be as near to $V_{CC}$ as possible.

The threshold voltage for Pin 46 is 0.7 V. The blanking period depends on the amplitude, as shown in Figure 3 (X and Y, respectively). A larger amplitude provides better consistency and control of the blanking period.

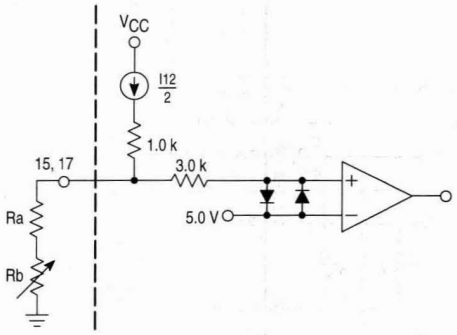
**Figure 3. Voltage for Flyback**




**5. Frequency Switch (Pin 14 to 17)**

There are two frequency switches available for screen size compensation for different timing standards. Each switch will turn on at the switch frequency set with its external resistor. See Figure 4.

**Figure 4. FH Switches**




The switch frequency is calculated as follow:

SF = Switch Frequency $\quad SF = \frac{5 \times 2 \times 122 \times 10^6}{Ra + Rb}$

In considering the ratio of Ra to Rb, the following parameters, and their tolerances, need to be clarified:

1. $I_{osc}$ ±10%
2. 5.0 $V_{ref}$ ±5%
3. $V_{hys}$ ±5%
4. Ra, Rb ±?%

Internally, the lock–in horizontal frequency will build up a current reference, and half of this current reference is used for setting up a voltage and then compared with the internal 5.0 $V_{ref}$. Looking at the four parameters above, the first three are IC related, while the last item depends on the external component tolerance.

By adding up the first three items, the value of Ra and Rb should be chosen to compensate for about 20% of system tolerance.

Therefore, if Ra is chosen to be 70% of the calculated value (Ra + Rb), Rb should be 60% of (Ra + Rb). That

means, the overall adjustment is about 70% to 130%, which provides additional ±10% margin.

During normal operation, the frequency switch will switch "off" when the pin voltage falls 60 mV below the 5.0 V reference voltage (≈ 4.94 V), and will switch "on" when the pin voltage rises to 40 mV above the 5.0 V reference (≈ 5.04 V).

An Example: Require Trip Point @ 35 kHz

$$I12 = \frac{35 \times 10^3}{122}\ \mu A$$

$$\text{Trip Point Reference Current} = \frac{I12}{2}$$

$$= \frac{35\ k}{122 \times 2}\ \mu A$$

$$Ra + Rb = \frac{5.0\ V}{\frac{35\ k}{122 \times 2}\ \mu A}$$

$$= 34857\ \Omega$$

$$\text{Hysteresis @ 35 kHz} = \frac{5.04 - 4.94\ V}{34857\ \Omega} \times \frac{122\ Hz}{\mu A}$$

$$\approx 350\ Hz$$

From above, Ra + Rb = 34857 Ω

Select Ra = 24 k, and Rb = 20 k Trim Pot

The Temperature Coefficient of the potentiometer can also be considered. If the value of the potentiometer and Ra vary by 1% (for example) over temperature, the error would be:

$$5 \times \left\{\frac{1}{34857 \times 0.99} - \frac{1}{34857 \times 1.01}\right\} \times \frac{122\ Hz}{\mu A}$$

$$\approx 350\ Hz$$

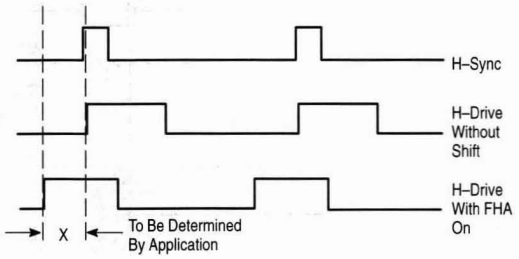
### 6. Horizontal Position Compensation for Selected Scan Frequency in Using FHA Switch

Refering to Figure1 (block diagram), there is an output from the FHA switch to the horizontal drive output. When the FHA switch is switched on, at a specified horizontal frequency, there is a 1/8th horizontal line shift of H–Ramp1. Referring to Figures 5 and 9, a shift of H–Ramp1 will result in a shift of the H–Drive output timing with respect to flyback input.

The exact H–Drive output shift will be determined by the PD2 voltage (Pin 45), which is generated by the flyback input and the internal Comp1 output. That is related to the H–Drive output transistor storage time.

This function is particularly useful for high frequency scan rates. The higher the frequency, the more significant the storage time becomes, compared to the horizontal scan time.

**Figure 5.**




### 7. Proper Horizontal Phase Control

The horizontal adjustment range depends on the phase angle between the H–Sync signal and the horizontal flyback input. In reality, the actual adjustment range is a combination of horizontal frequency, front porch/back porch timing, flyback pulse width, and horizontal output transistor storage time. The following paragraph conveys the concept for normal operation.

There are two clamping situations for video signals. In case 1, separate VTTL and HTTL sync are provided, the video signal is clamped at sync tip, and the dc voltage built up is used for black level reference. In this instance, the clamp pulse has the same pulse width as H–Sync, and nearly the same position. This clamp pulse is blanked out internally. In order to allow the video output to complete the blanking action during horizontal retrace, the horizontal phase should not be over–adjusted. See Figure 6 for a pictorial perception. Accordingly, the total horizontal position adjustment range is calculated as the sum of $\Delta t1$ and $\Delta t2$.

Should the phase of horizontal flyback/H–Sync move further left or right from the normal adjustment range, the black level reference voltage will be restored, and consequently a slightly brighter than screen dark region will be observed on–screen. See Figure 7 for pictorial explanation.

$$\text{Horizontal Blanking Time} = FP_{time} + \text{Sync Width} + BP_{time} = T_{HB}$$

Criterion for Normal Operation:

$$|\Delta t1| < \frac{T_{HB}}{2} \qquad |\Delta t2| < \frac{T_{HB}}{2}$$

In other words, the left/right 0.7 V threshold flyback reference should be within the H–Sync pulse (shaded area of Figure 6).

9

**Figure 6. Horizontal Position Adjustment at Normal Operation**

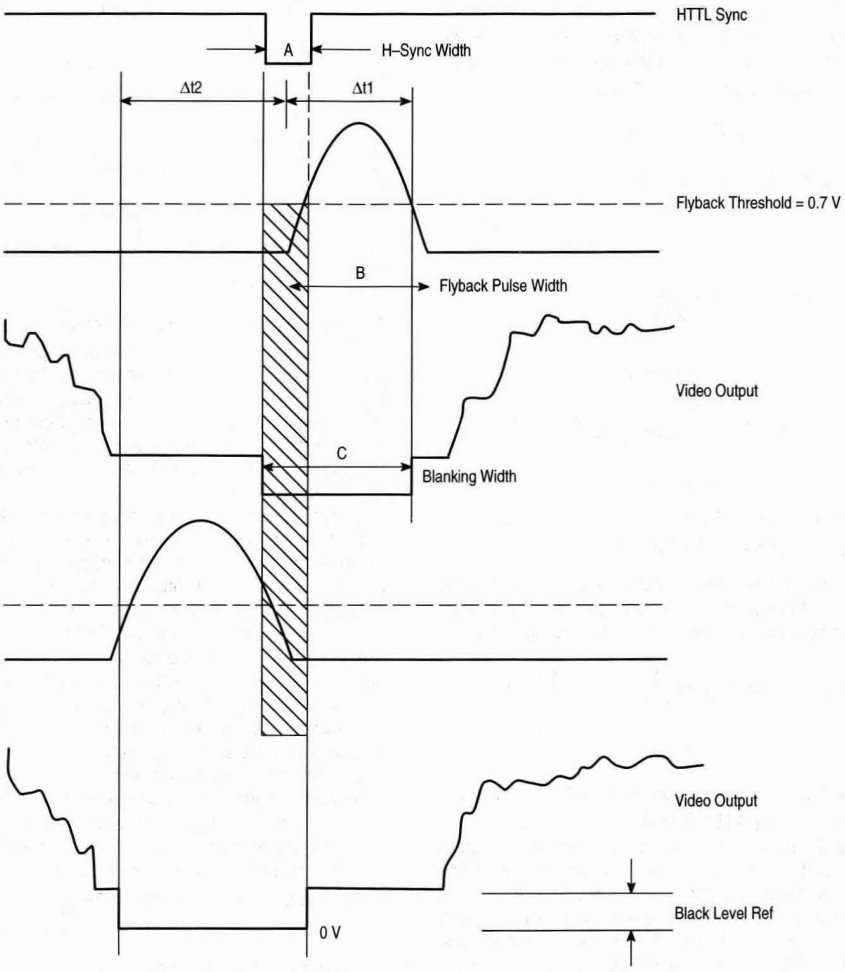
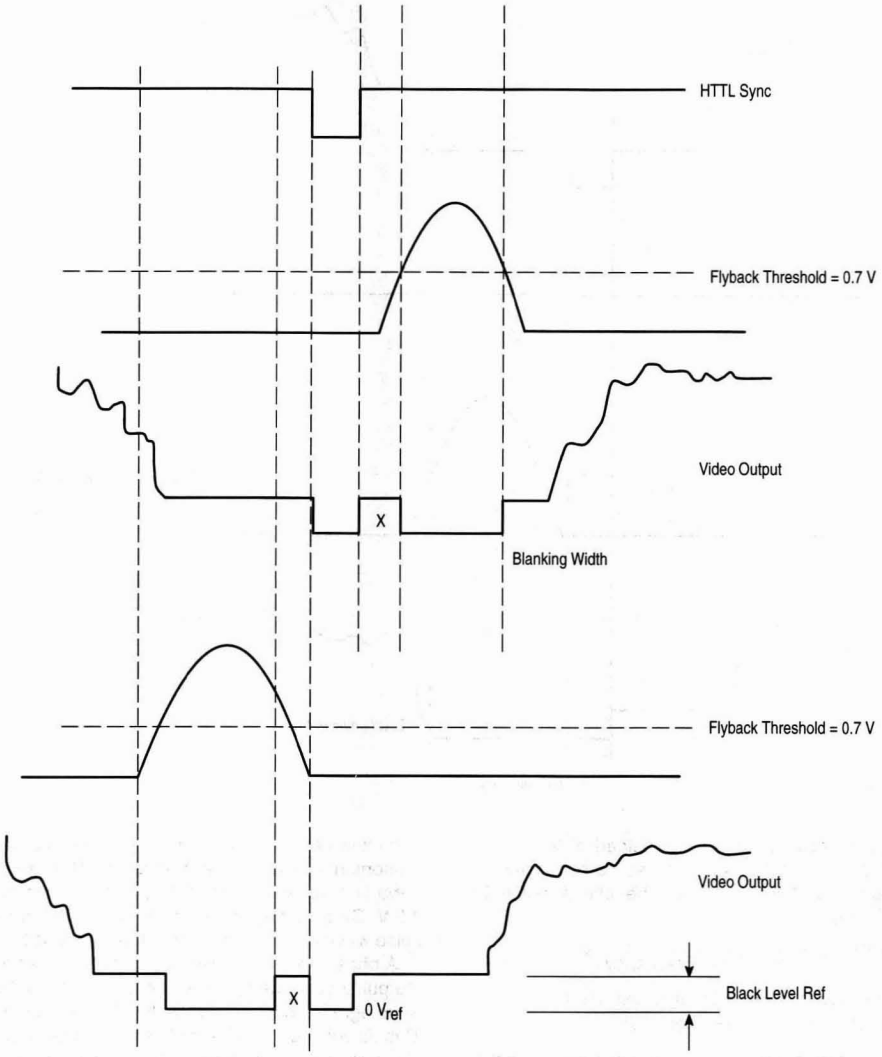
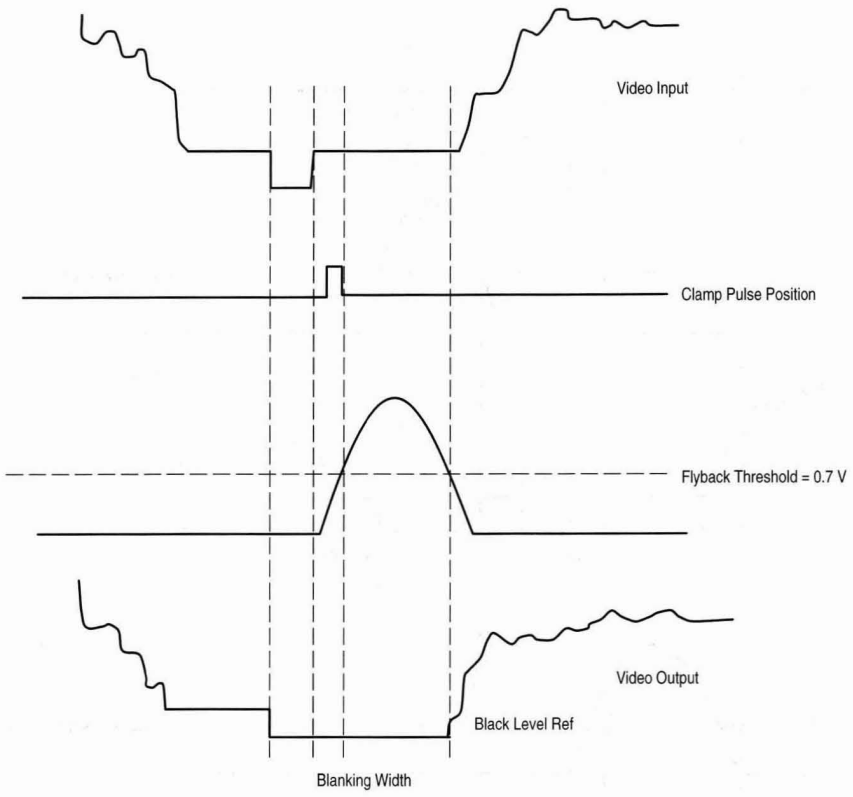


**Figure 7. Horizontal Position Adjustment at Overscan Operation**




**NOTE:** Region X will appear as bright vertical stripe.

**Figure 8.**






In case 2, composite sync is used instead of VTTL and HTTL sync, the clamp pulse is located at the backporch of the video signal, and the width of the clamp pulse is calculated as follows:

$$\text{Clamp Pulse Width} = \frac{1}{64 \times \text{Line Frequency}} \times 3$$

Blanking Width = Sync Width + Clamp Pulse Width + Flyback Threshold (0.7 V) (See Figure 8)

From the above diagram, it can be seen that the horizontal position adjustment is basically the same as case 1 except slightly wider with the addition of clamp pulse blanking.

**8. Horizontal Timing Relationship for Phase Detector 2**

The following paragraphs explain the PLL2 mechanism. Figure 9 portrays the timing signals of various parts of the IC.

In using the H–Sync pulse, which is generated from PLL1, a horizontal ramp 1 signal is created. H–Ramp1 starts at 1/4th line before H–Sync and the ramping slope is directly proportional to horizontal frequency. The lower tip of this ramp is at approximately 1.2 V, and the amplitude is about 4.2 V. By adjusting the dc bias to the H–Phase control, a pulse waveform is derived from this H–Ramp1.

A phase detector is used to compare the phase between the pulse generated above, and the incoming flyback pulse. An integrating capacitor is applied to generate a dc voltage. This dc voltage, PD2F output, is used to slice the H–Ramp1 signal in order to generate Comp2 output pulse.

A second ramp signal, H–Ramp2, is triggered from this Comp2 output. By applying a dc voltage (H–Width control) to H–Ramp2, the Comp3 output pulses are generated.

The H–Drive output is formed by the rising edge of Comp2 output and the rising edge of Comp3 output.

It can be seen from Figure 9, if the H–Phase control is over or under driven, it will reach the upper/lower tip of H–Ramp1, and thus PLL2 will be disturbed.

**Figure 9. Horizontal Timing for PLL2 Internal Sections**

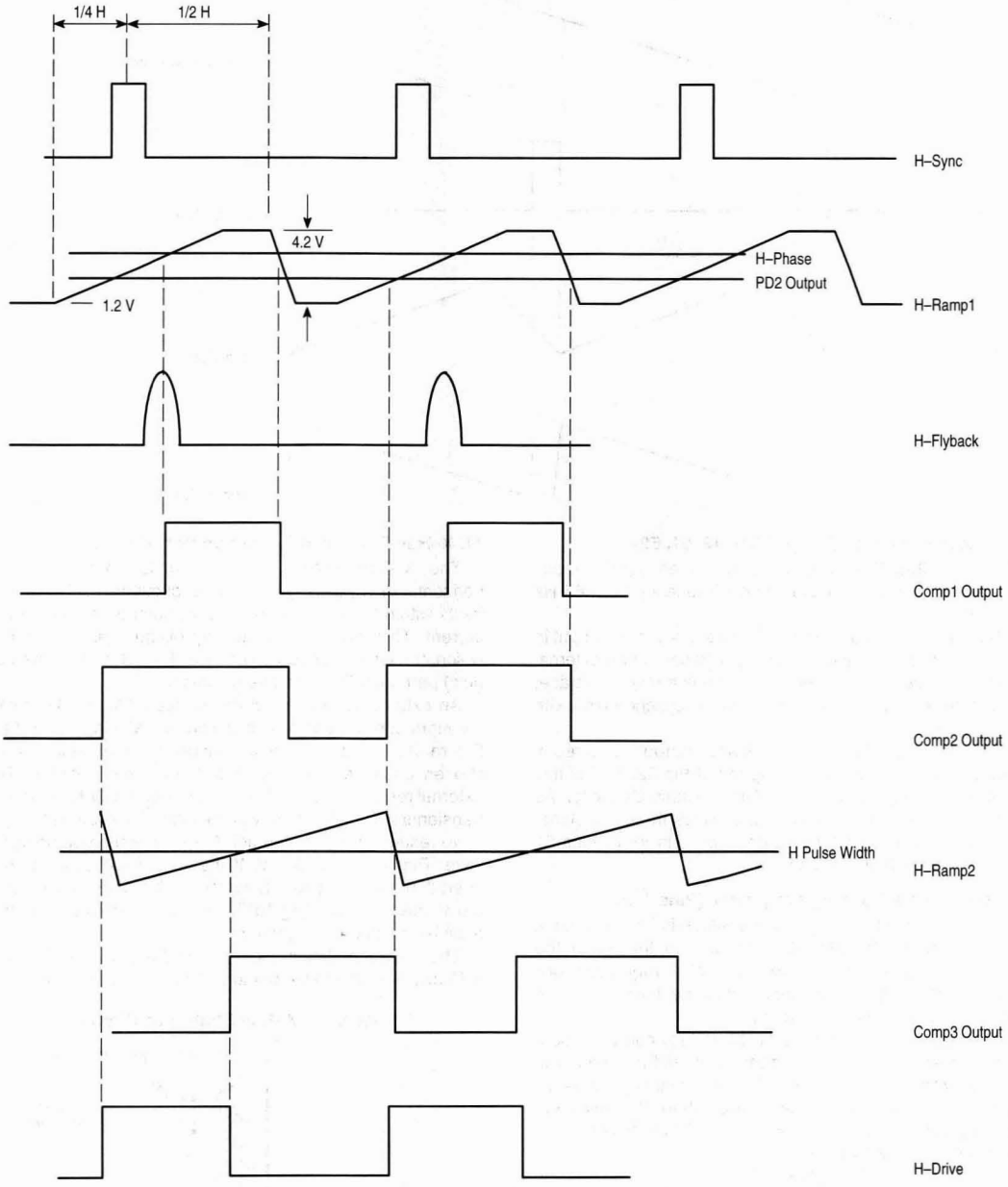
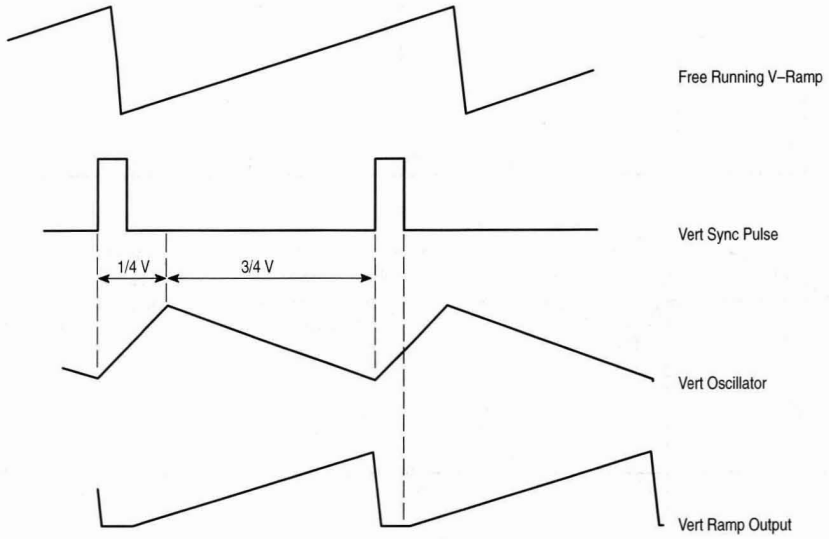


**Figure 10. Vertical Section**




**9. Vertical Frequency Range (Pins 48, 51, 52)**

The MC13081X vertical oscillator is an injection–lock type. The device can handle vertical frequency from 45 Hz to 100 Hz.

The internal ramp generator will generate a ramp output in the absence of a V–Sync signal. Upon receiving an external vertical sync pulse, the ramp up portion is forced to retrace, and therefore, the vertical ramp output is synchronized with incoming V–Sync.

The slope of the Vertical Ramp output is directly proportional to the current flowing out of Pin 52. Half of this current is used to charge up the Vertical Ramp Capacitor. As the charging current is increased, so does the ramp slope. External feedback can be provided from Pin 48 to Pins 51 and 52 for linearity adjustment.

**10. Vertical Free Running Frequency (Pins 1, 2)**

The purpose of the vertical oscillator is to maintain a vertical ramp to the deflection circuitry in the event the vertical sync is not present. Because of the injection–lock type, the free running frequency must be lower than the system's lowest vertical frequency.

While various combinations of C4 and R9 can produce a given frequency, it is recommended C4 be 0.1 μF in order to obtain practical values for R9. The free running frequency should be set at about 10% lower than the minimum operating vertical frequency (54 Hz for a 60 Hz system).

R9 is then calculated from:

$$R9 = \frac{V_{CC} - 1.4}{96 \times C4 \times FV} - 2.5\ k$$

Connecting a potentiometer, (VR2) provides "Vertical Hold" adjustment.

**11. X–Ray Shutdown Protection (Pin 41)**

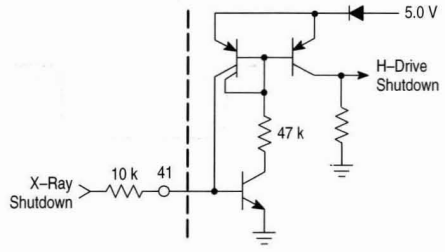
The X–Ray input (Pin 41) permits shutting off the horizontal drive, usually by external circuitry which monitors faults within the high voltage supply, such as excess anode current. This input is activated by taking it above ≈ 0.6 V which causes the drive transistor at Pin 43 to be turned on (low) permanently by an internal latch.

An external resistor must be connected to Pin 41 to limit the input current, and to assist with the latching action (see Figure 11). 10 kΩ is a typical value, but the value can be chosen based on the specifies of the driving circuit. The external resistor reduces the sensitivity of Pin 41 to noise and transients which may otherwise result in false latches.

To resume normal operation (after correction of the fault), lower Pin 41 below 0.4 V. If the external circuit's normal operation does not take it below 0.4 V, but does take it below 0.6 V, then recycle $V_{CC}$ "off"–"on". If the pin is not used, it must be connected to ground.

The minimum holding current to keep the latch on is ≈ 70 μA, while the minimum turn–on current is ≈ 0.4 μA.

**Figure 11. X–Ray Shutdown Circuit**



MOTOROLA

# MC13280AY
# MC13281A/B

## 80/100 MHz VIDEO PROCESSOR

*Advance Information*

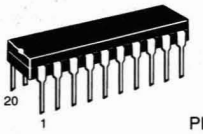
# 80/100 MHz Video Processor

The MC13280AY and MC13281A/B are three channel wideband amplifiers designed for use as a video pre–amplifier in high resolution RGB color monitors.

**Features:**

- 4.0 Vpp Output Swing
- 3.5 ns Rise/Fall Time, 100 MHz Bandwidth (MC13281A/B)
- 4.3 ns Rise/Fall Time, 80 MHz Bandwidth (MC13280AY)
- Subcontrast Controls for Each Channel
- Main Contrast Control
- Blanking and Clamping Inputs
- Packages: NDIP–24 and NDIP–20
- A Single PC Board Pattern Can Accept the MC13281A and the MC13282A (Video Amplifier with OSD)

**P SUFFIX**
PLASTIC PACKAGE
CASE 724

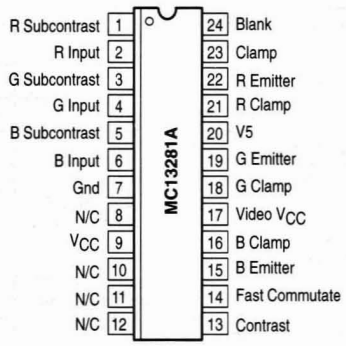



**P SUFFIX**
PLASTIC PACKAGE
CASE 738

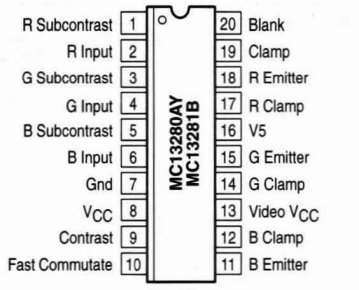
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13280AYP | $T_A$ = 0° to +70°C | Plastic DIP |
| MC13281AP | | Plastic DIP |
| MC13281BP | | Plastic DIP |

**PIN CONNECTIONS**




(Top View)




(Top View)

**ABSOLUTE MAXIMUM RATINGS**

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$<br>Video $V_{CC}$ | –0.5, 10<br>–0.5, 10 | Vdc |
| Voltage at Video Amplifier Inputs | 2, 4, 6 | –0.5, +5.0 | Vdc |
| Collector–Emitter Current (Three Channels) | Video $V_{CC}$ | 120 | mA |
| Storage Temperature | – | –65 to +150 | °C |
| Junction Temperature | – | 150 | °C |

**NOTES:** 1. Devices should not be operated at these limits. Refer to "Recommended Operating Conditions" section for actual device operation.

2. ESD data available upon request.

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**RECOMMENDED OPERATING CONDITIONS**

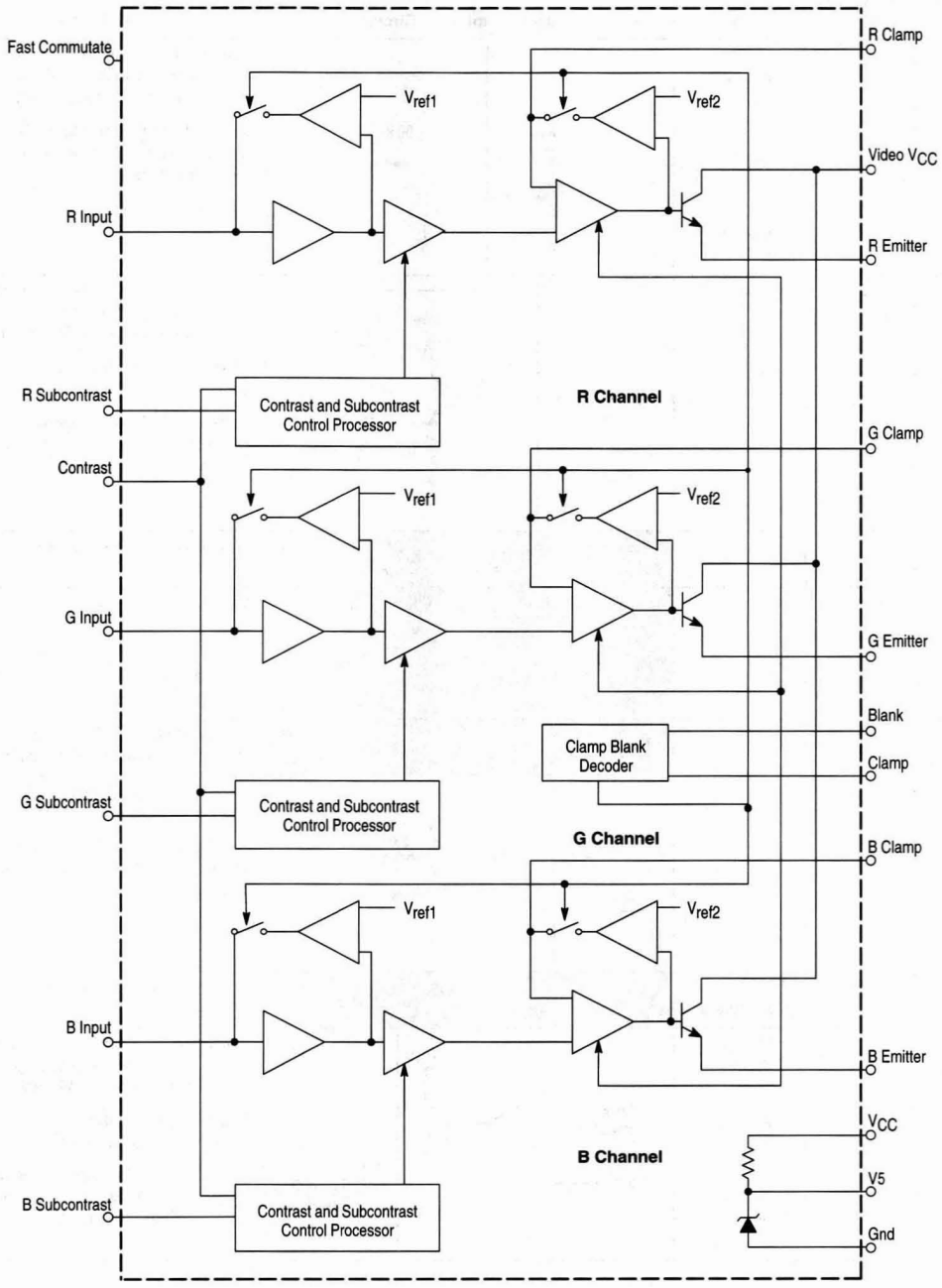
| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC}$, Video $V_{CC}$ | 7.6 | 8.0 | 8.4 | Vdc |
| Contrast Control | Contrast | 0 | – | 5.0 | Vdc |
| Subcontrast Control | 1, 3, 5 | 0 | – | 5.0 | Vdc |
| Blanking Input Signal Amplitude | Blank | 0 | – | 5.0 | V |
| Clamping Input Signal Amplitude | Clamp | 0 | – | 5.0 | V |
| Video Signal Amplitude (with 75 Ω Termination) | 2, 4, 6 | – | 0.7 | 1.0 | Vpp |
| Collector–Emitter Current (Total for Three Channels) | Video $V_{CC}$ | 0 | – | 50 | mA |
| Clamp Pulse Width | Clamp | 500 | – | – | ns |
| Operating Ambient Temperature | – | 0 | – | 70 | °C |

**ELECTRICAL CHARACTERISTICS** (Refer to Test Circuit Figure 1, $T_A$ = 25°C, $V_{CC}$ = 8.0 Vdc.)

| Characteristic | Condition | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Input Impedance | – | 2, 4, 6 | 100 | – | – | kΩ |
| Internal DC Bias Voltage | | | – | 2.4 | – | Vdc |
| Output Signal Amplitude | V2, V4, V6 = 0.7 Vpp<br>V1, V3, V5 = 5.0 V<br>Contrast = 5.0 V | R, G, B Emitters | 3.6 | 4.0 | – | Vpp |
| Voltage Gain | | | – | 5.6 | – | V/V |
| Contrast Control | Contrast = 5.0 to 0 V<br>V1, V3, V5 = 5.0 V | Contrast | – | –26 | – | dB |
| Subcontrast Control | V1, V3, V5 = 5.0 to 0 V<br>Contrast = 5.0 V | 1, 3, 5 | – | –26 | – | dB |
| Emitter DC Level | – | – | 1.0 | 1.2 | 1.4 | Vdc |
| Blanking Input Threshold | – | Blank | – | 1.25 | – | V |
| Clamping Input Threshold | – | Clamp | – | 3.75 | – | V |
| Video Rise Time<br>MC13280AY<br>MC13281A/B | V2, V4, V6 = 0.7 Vpp<br>$V_{out}$ = 4.0 Vpp<br>$R_L$ > 300 Ω, $C_L$ < 5.0 pF | R, G, B Emitters | <br>–<br>– | <br>4.3<br>3.5 | <br>–<br>– | ns |
| Video Fall Time<br>MC13280AY<br>MC13281A/B | V2, V4, V6 = 0.7 Vpp<br>$V_{out}$ = 4.0 Vpp<br>$R_L$ > 300 Ω, $C_L$ < 5.0 pF | R, G, B Emitters | <br>–<br>– | <br>4.3<br>3.5 | <br>–<br>– | ns |
| Video Bandwidth<br>MC13280AY<br>MC13281A/B | V2, V4, V6 = 0.7 Vpp<br>V1, V3, V5, Contrast = 5.0 V<br>$R_L$ > 300 Ω, $C_L$ < 5.0 pF | R, G, B Emitters | <br>–<br>– | <br>80<br>100 | <br>–<br>– | MHz |
| Power Supply Current | $V_{CC}$, Video $V_{CC}$ = 8.0 V | – | – | 70 | – | mA |

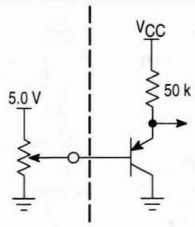
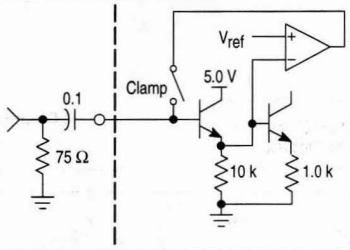
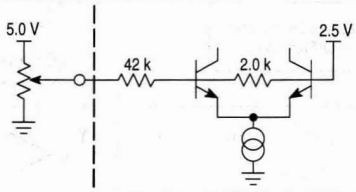
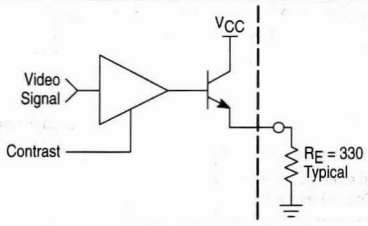
**NOTE:** It is recommended to use a double sided PCB layout for high frequency measurement (e.g., rise/fall time, bandwidth).

**Figure 1. Internal Block Diagram**




This device contains 272 active transistors.

## PIN FUNCTION DESCRIPTION

| MC13280AY MC13281B Pin | MC13281A Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|---|
| 1<br>3<br>5 | 1<br>3<br>5 | R Subcontrast Control<br>G Subcontrast Control<br>B Subcontrast Control |  | These pins provides a maximum of 26 dB attenuation to vary the gain of each video amplifier separately.<br>Input voltage is from 0 to 5.0 V. Increasing the voltage will increase the contrast level. |
| 2<br>4<br>6 | 2<br>4<br>6 | R Input<br>G Input<br>B Input |  | The input coupling capacitor is used for input clamping storage. The maximum source impedance is 100 Ω.<br>Input polarity of the video signal is positive.<br>Nominal 0.7 Vpp input signal is recommended (maximum 1.0 Vpp). |
| 7 | 7 | Ground | | Ground pin. Connect to a clean, solid ground. |
| N/A | 8<br>10<br>11<br>12 | N/C<br>N/C<br>N/C<br>N/C | | Connected to ground. |
| 8 | 9 | VCC | | Connect to 8.0 Vdc supply, ±5%. Decoupling is required at this pin. |
| 9 | 13 | Contrast |  | Overall Contrast Control for the three channels.<br>The input range is 0 V to 5.0 V. An increase of voltage increases the contrast. |
| 10 | 14 | Fast Commutate | | Must be connected to ground. |
| 11<br>15<br>18 | 15<br>19<br>22 | B Emitter Output<br>G Emitter Output<br>R Emitter Output |  | The video outputs are configured as emitter–followers with a driving capability of about 15 mA each.<br>The dc voltage at these three emitters is set to 1.2 V (black level).<br>The dc current through the output stage is determined by the emitter resistors (typically 330 Ω). |

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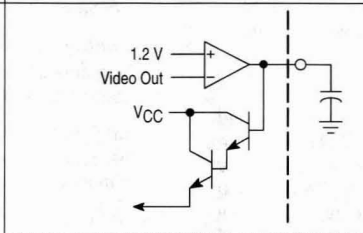
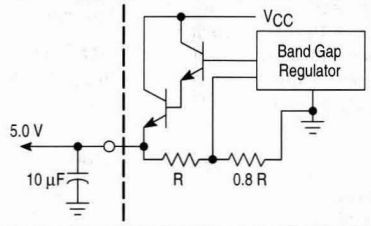
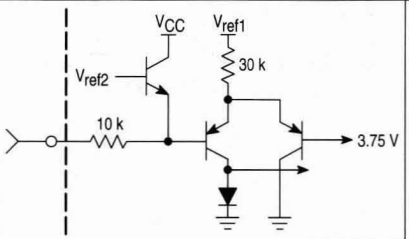
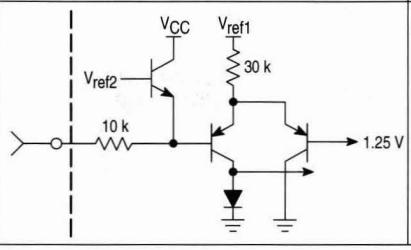
**PIN FUNCTION DESCRIPTION (continued)**

| MC13280AY MC13281B Pin | MC13281A Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|---|
| 12<br><br>14<br><br>17 | 16<br><br>18<br><br>21 | B Clamp Capacitor<br><br>G Clamp Capacitor<br><br>R Clamp Capacitor |  | A 100 nF capacitor is connected to each of these pins.<br><br>The capacitor is used for video output dc restoration. |
| 13 | 17 | Video $V_{CC}$ | | Connect to 8.0 V dc supply, ±5%. The $V_{CC}$ is for the video output stage. It is internally connected to the collectors of the output transistors. |
| 16 | 20 | 5.0 $V_{ref}$ (V5) |  | 5.0 V regulator. Minimum 10 µF capacitor is required for noise filtering and compensation. It can source up to 20 mA but not sink current. Output impedance is ≈ 10 Ω. Recommended for use as a voltage reference only. |
| 19 | 23 | Clamp |  | This pin is used for video clamping.<br><br>The threshold clamping level is 3.75 V. |
| 20 | 24 | Blank |  | This pin is used for video blanking.<br><br>The threshold blanking level is 1.25 V. |

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## FUNCTIONAL DESCRIPTION

The MC13280AY and MC13281A/B are composed of three video amplifiers, clamping and blanking circuitry with contrast and subcontrast controls. Each video amplifier is designed to have a –3.0 dB bandwidth of 100 MHz (MC13281, 80 MHz for the MC13280) with a gain of up to about 5.6 V/V, or 15 dB.

### Video Input

The video input stages are high impedance and designed to accept a maximum signal of 1.0 Vpp with 75 Ω termination (typically) provided externally. During the clamping period, a current is provided to the input capacitor by the clamping circuit which brings the input to a proper dc level (nominal 2.0 V). The blanking and clamping signals are to be provided externally, with their thresholds at 1.25 V and 3.75 V, respectively.

### Video Output

The video output stages are configured as emitter–followers, with a driving capability of about 15 mA for each channel. The dc voltage at these three emitters is set to 1.2 V (black level). The dc current through each output stage is determined by the emitter resistor (typically 330 Ω).

### Contrast Control

The contrast control varies the gain of three video amplifiers from a minimum of 0.3 V/V to a maximum of 5.6 V/V when all subcontrast levels are set to 5.0 V.

### Subcontrast Control

Each subcontrast control provides a maximum of 26 dB attenuation on each video amplifier separately.

### Clamp Pulse Input

The clamping pulse is provided externally, and the pulse width must be no less than 500 ns.

### Blank Pulse Input

The blanking pulse is used to blank the video signal during the horizontal sync period, or used as a control pin for video mute function.

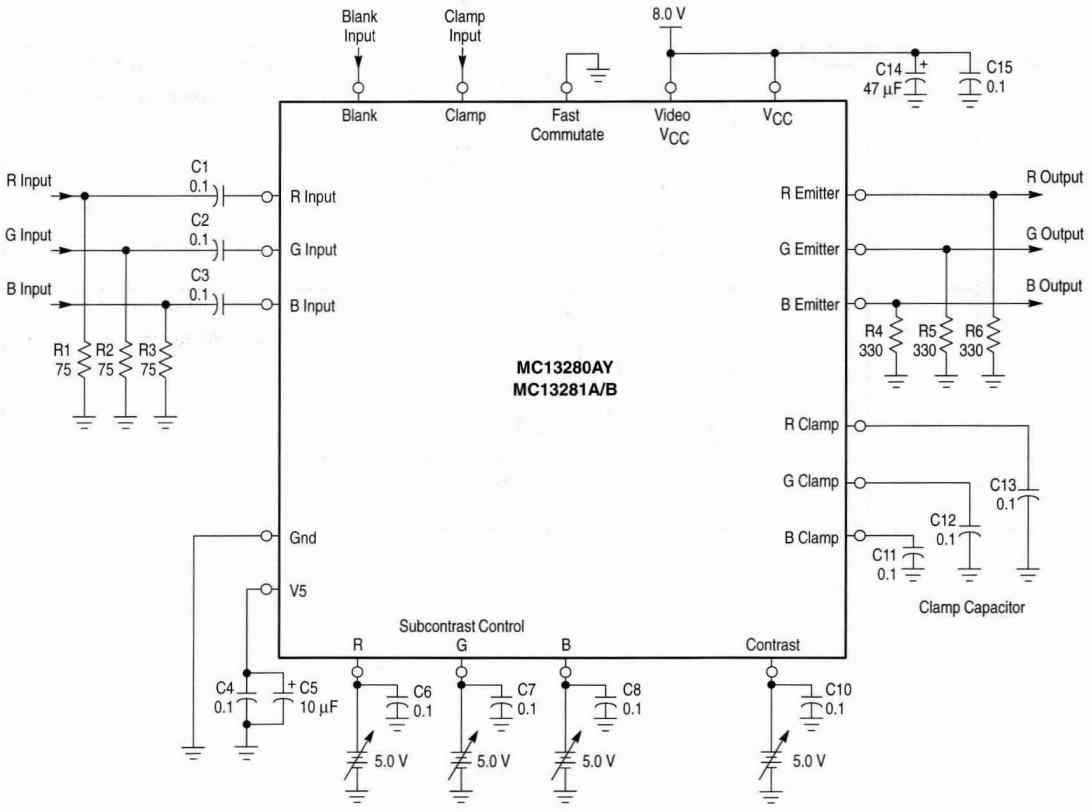
### Fast Commutate

This pin should be connected to ground.

### Power Supplies

$V_{CC}$ and Video $V_{CC}$ supplies are to be 8.0 V ±5%.

**Figure 2. Test Circuit**



## APPLICATION INFORMATION

### PCB Layout

Care should be taken in the PCB layout to minimize the noise effects. The most sensitive pins are $V_{CC}$, Video $V_{CC}$, V5 and Clamp. It is strongly recommended to make a ground plane and connect $V_{CC}$/Video $V_{CC}$ and ground traces, to the power supply directly. Separate power supply traces should be used for $V_{CC}$ and Video $V_{CC}$ and decoupling capacitors should be connected as close as possible to the device. Multi–layer ceramic and tantalum capacitors are recommended. V5 is designed as a 5.0 V voltage reference for contrast, and RGB subcontrast controls, so the same precautions for $V_{CC}$ should also be applied at this pin. The Clamp capacitors should be connected to ground close to IC's ground pin, or power supply ground. The copper trace of video signal inputs and outputs should be as short as possible and separated by ground traces to avoid any RGB cross–interference. A double sided PCB should be used to optimize the device's performance.

### RGB Input and Output

The RGB output stages are designed as emitter–followers to drive the CRT driver circuitry directly. The emitter resistors used are 330 Ω (typically) and the driving current is 15 mA maximum for each channel. The loading impedance connected to the output stages should be greater than 330 Ω and less than 5.0 pF for optimum performance (e.g., rise/fall time, bandwidth, etc.). Decreasing the resistive load will reduce the rise/fall time by increasing the driving current, but the output stage may be damaged due to increasing power dissipation at the same time. The frequency response is affected by the loading capacitance. The typical value is 3.0 to 5.0 pF. Figure 3 shows a typical interface with a video output driver. For high resolution color monitor application, it is recommended to use coaxial cable or shielded cable for input signal connections.

### Clamp and Blank Input

The clamp input is normally (except for Sync–on–Green) connected to a positive horizontal sync pulse and has a threshold level of 3.75 V. It is used as a timing reference for the dc restoration process, so it cannot be an open circuit. If Sync–on–Green timing mode is used, the clamping pulse should be located at the horizontal back porch period instead of horizontal sync. Otherwise, the black level will be clamped at the wrong dc level.

The blank input is used as a video mute, or horizontal blanking control pin, and is normally connected to a blanking pulse generated from the flyback or MCU. The threshold level is 1.25 V. The blanking pulse width should be equal to the flyback retrace period to make sure that the video signal is blanked properly during retrace. It is necessary to limit the amplitude and avoid any negative undershoot if the flyback pulse is used. The blanking input pin cannot accept a negative voltage. This pin should be grounded if it is not used.

**Figure 3. Interfacing with Video Output Drivers**

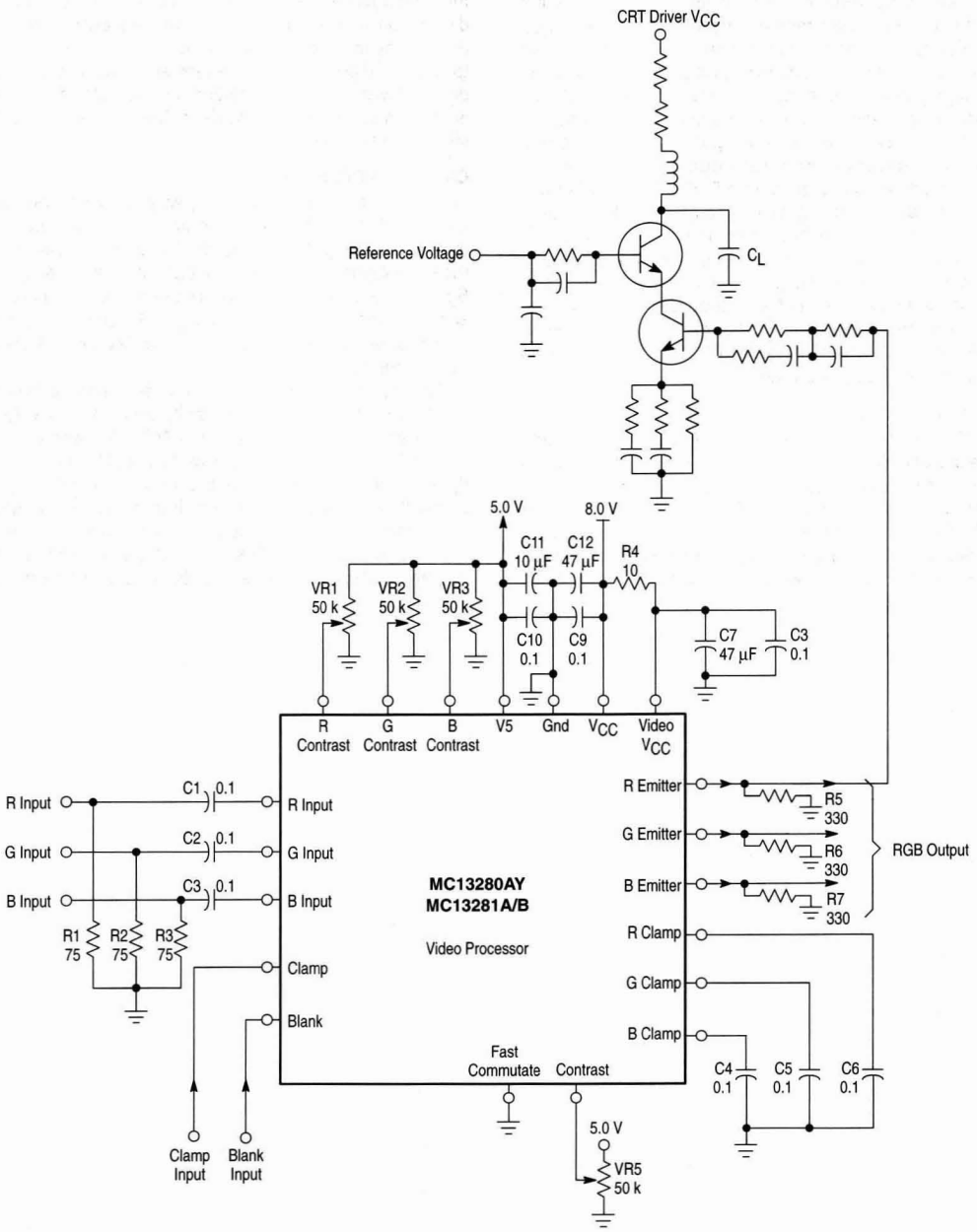


**Figure 4. RGB In/Out Linearity**

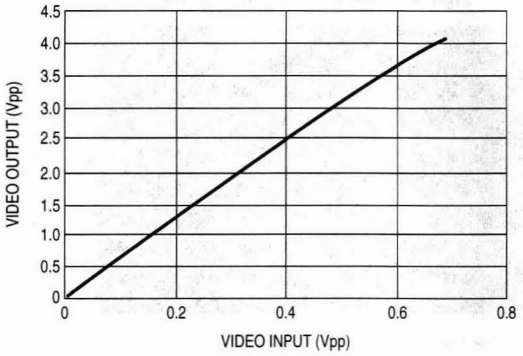



**Figure 5. Contrast Control**

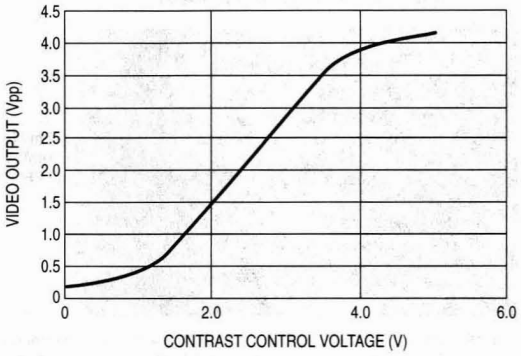



**Figure 6. Subcontrast Control**

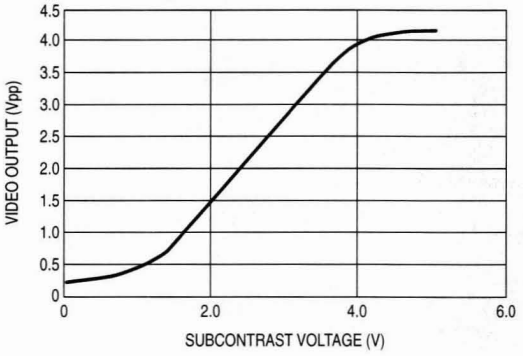
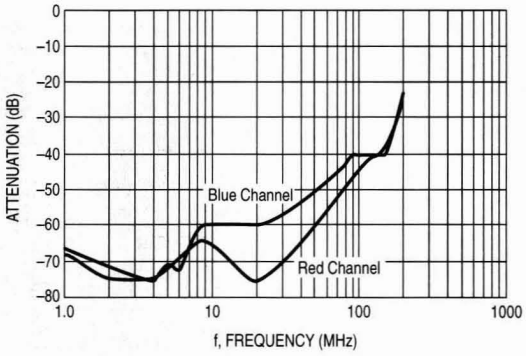
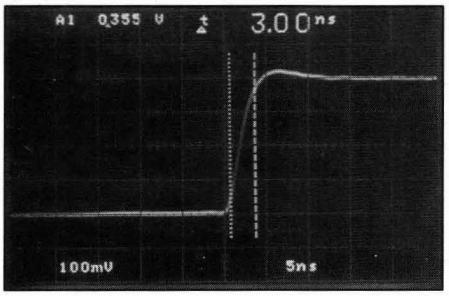



**Figure 7. Crosstalk From Green to Red and Blue Channels**



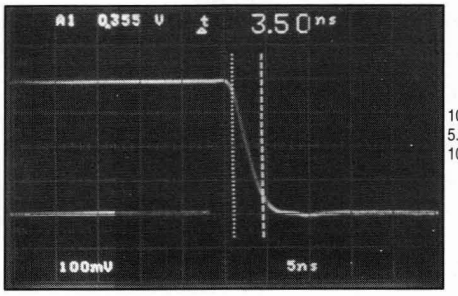

9

**Figure 8. Rise Time for MC13281B**




100 mV/DIV
5.0 ns/DIV
10x PROBE

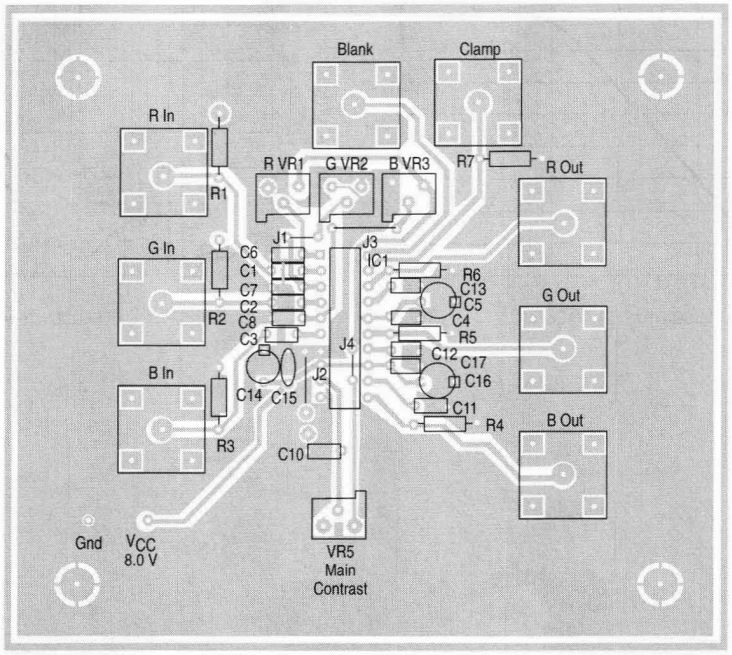
**Figure 9. Fall Time for MC13281B**




100 mV/DIV
5.0 ns/DIV
10x PROBE

**NOTE:** Recommend to use a double sided PCB without any socket for rise/fall time measurements, using an input pulse with 1.5 ns rise/fall time and an active probe with 1.7 pF capacitance loading.

**Figure 10. Single Sided PCB Layout (Component Side) for MC13280AY, MC13281B**




**NOTE:** J = Jumper

MOTOROLA

# MC13282A

*Advance Information*

# 100 MHz Video Processor with OSD Interface

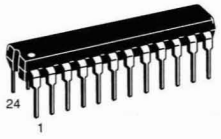
The MC13282A is a three channel wideband amplifier designed for use as a video pre–amp in high resolution RGB color monitors.

**Features:**

- 4.0 Vpp Output with 100 MHz Bandwidth
- 3.5 ns Rise/Fall Time
- Subcontrast Control for Each Channel
- Blanking and Clamping Inputs
- Contrast Control
- OSD Interface with 50 MHz Bandwidth
- OSD Contrast Control
- Package: NDIP–24

**100 MHz VIDEO PROCESSOR WITH OSD INTERFACE**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 724

9

### ABSOLUTE MAXIMUM RATINGS

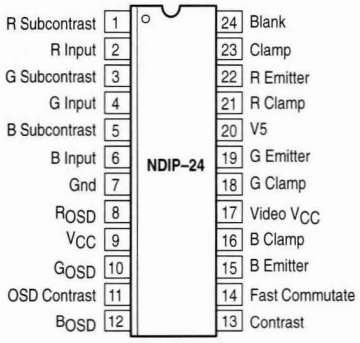
| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage – $V_{CC}$ | 9 | –0.5, 10 | Vdc |
| Power Supply Voltage – Video $V_{CC}$ | 17 | –0.5, 10 | Vdc |
| Voltage at Video Amplifier Inputs | 2, 4, 6, 8, 10, 12 | –0.5, +5.0 | Vdc |
| Collector–Emitter Current (Three Channels) | 17 | 120 | mA |
| Storage Temperature | – | –65 to +150 | °C |
| Junction Temperature | – | 150 | °C |

**NOTES:** 1. Devices should not be operated at these limits. Refer to "Recommended Operating Conditions" section for actual device operation.
2. ESD data available upon request.

### RECOMMENDED OPERATING CONDITIONS

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | 9, 17 | 7.6 | 8.0 | 8.4 | Vdc |
| Contrast Control | 13 | 0 | – | 5.0 | Vdc |
| Subcontrast Control | 1, 3, 5 | 0 | – | 5.0 | Vdc |
| Blanking Input Signal Amplitude | 24 | 0 | – | 5.0 | V |
| Clamping Input Signal Amplitude | 23 | 0 | – | 5.0 | V |
| Video Signal Amplitude (with 75 Ω Termination) | 2, 4, 6 | – | 0.7 | 1.0 | Vpp |
| OSD Signal Input | 8, 10, 12 | – | TTL | – | V |
| Collector–Emitter Current (Total for Three Channels) | 17 | 0 | – | 50 | mA |
| Clamping Pulse Width | 23 | 500 | – | – | ns |
| Operating Ambient Temperature | – | 0 | – | 70 | °C |

### PIN CONNECTIONS



(Top View)

### ORDERING INFORMATION

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13282AP | $T_A$ = 0° to +70°C | Plastic DIP |

**ELECTRICAL CHARACTERISTICS** (Refer to Test Circuit Figure 1, $T_A$ = 25°C, $V_{CC}$ = 8.0 Vdc.)

| Characteristic | Condition | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Input Impedance | – | 2, 4, 6 | 100 | – | – | kΩ |
| Internal DC Bias Voltage | | | – | 2.4 | – | Vdc |
| Output Signal Amplitude | V2, V4, V6 = 0.7 Vpp<br>V1, V3, V5, V13 = 5.0 V<br>V14 = 0 V | 15, 19, 22 | 3.6 | 4.0 | – | Vpp |
| Voltage Gain | | | – | 5.6 | – | V/V |
| Contrast Control | V13 = 5.0 to 0 V<br>V1, V3, V5 = 5.0 V | 13 | – | –26 | – | dB |
| Subcontrast Control | V1, V3, V5 = 5.0 to 0 V<br>V13 = 5.0 V | 1, 3, 5 | – | –26 | – | dB |
| Emitter DC Level | – | 15, 19, 22 | 1.0 | 1.2 | 1.4 | Vdc |
| Blanking Input Threshold | – | 24 | – | 1.25 | – | V |
| Clamping Input Threshold | – | 23 | – | 3.75 | – | V |
| Video Rise Time | V2, V4, V6 = 0.7 Vpp<br>$V_{out}$ = 4.0 Vpp<br>$R_L$ > 300 Ω, $C_L$ < 5.0 pF | 15, 19, 22 | – | 3.5 | – | ns |
| Video Fall Time | | | – | 3.5 | – | |
| Video Bandwidth | V2, V4, V6 = 0.7 Vpp<br>V1, V3, V5, V13 = 5.0 V<br>V14 = 0 V<br>$R_L$ > 300 Ω, $C_L$ < 5.0 pF | 15, 19, 22 | – | 100 | – | MHz |
| OSD Rise Time | V8, V10, V12 = TTL Level<br>V11 = 5.0 V, V14 = 5.0 V | 15, 19, 22 | – | 7.0 | – | ns |
| OSD Fall Time | | | – | 7.0 | – | |
| OSD Bandwidth | V8, V10, V12 = TTL Level<br>V11 = 5.0 V, V14 = 5.0 V | 15, 19, 22 | – | 50 | – | MHz |
| OSD Propagation Delay | – | – | – | 17 | – | ns |
| Power Supply Current | $V_{CC}$, Video $V_{CC}$ = 8.0 V | 9, 17 | – | 70 | – | mA |

**NOTE:** It is recommended to use a double sided PCB layout for high frequency measurement (e.g., rise/fall time, bandwidth).

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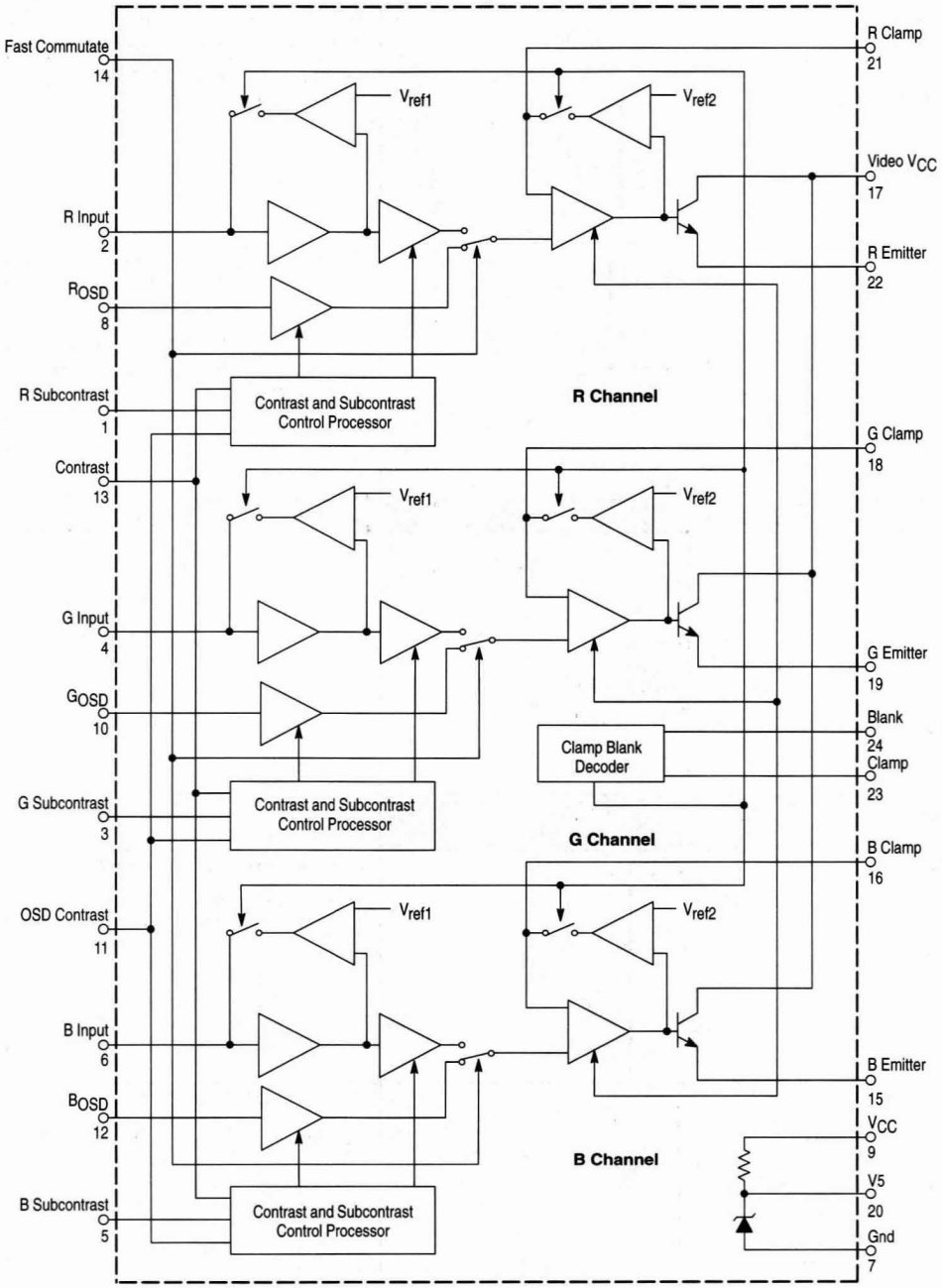
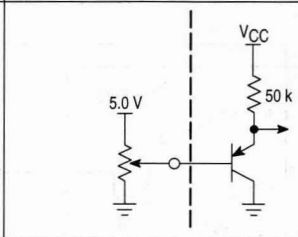
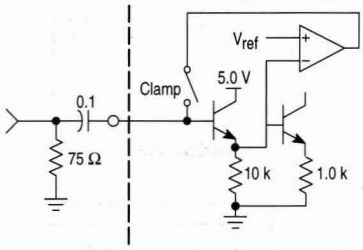
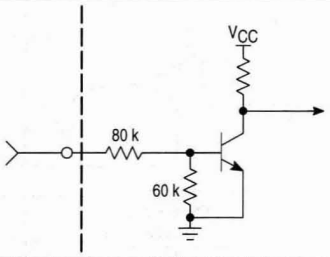
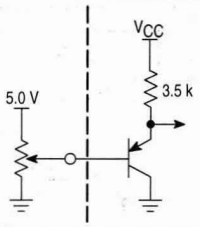
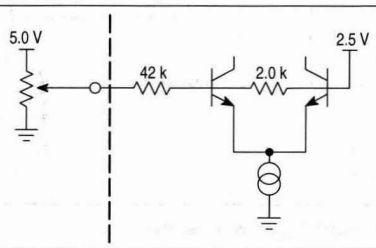
**Figure 1. Internal Block Diagram**




This device contains 272 active transistors.

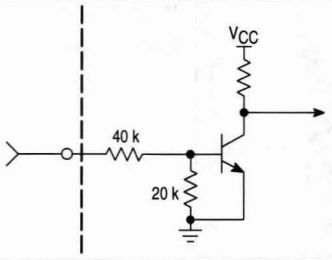
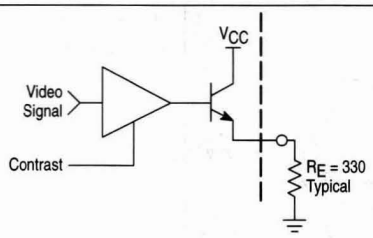
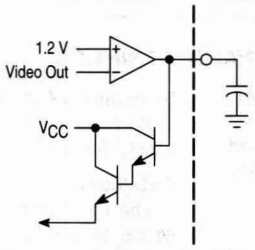
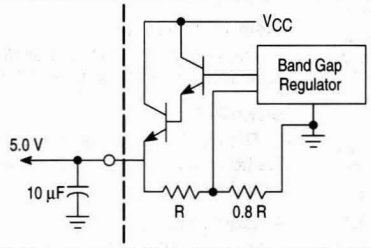
9

## PIN FUNCTION DESCRIPTION

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 1<br>3<br>5 | R Subcontrast Control<br>G Subcontrast Control<br>B Subcontrast Control |  | These pin provides a maximum of 26 dB attenuation to vary the gain of each video amplifier separately.<br>Input voltage is from 0 to 5.0 V. Increasing the voltage will increase the contrast level. |
| 2<br>4<br>6 | R Input<br>G Input<br>B Input |  | The input coupling capacitor is used for input clamping storage. The maximum source impedance is 100 Ω.<br>Input polarity of the video signal is positive.<br>Nominal 0.7 Vpp input signal is recommended (maximum 1.0 Vpp). |
| 7 | Ground | | Ground pin. Connect to a clean, solid ground. |
| 8<br>10<br>12 | $R_{OSD}$ Input<br>$G_{OSD}$ Input<br>$B_{OSD}$ Input |  | These inputs are standard TTL level. |
| 9 | $V_{CC}$ | | Connect to 8.0 Vdc supply, ±5%. Decoupling is required at this pin. |
| 11 | OSD Contrast |  | On Screen Display contrast control.<br>Input voltage is from 0 to 5.0 V. Increasing the voltage will increase the contrast of the OSD signal. |
| 13 | Contrast |  | Overall Contrast Control for the three channels.<br>The input range is 0 V to 5.0 V. An increase of voltage increases the contrast. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 14 | Fast Commutate |  | This pin is used in conjunction with the RGB OSD inputs. It is a high speed switch used for overlaying text on picture. A logic low selects Pins 2, 4, 6. A logic high selects Pins 8, 10, 12. |
| 15<br>19<br>22 | B Emitter Output<br>G Emitter Output<br>R Emitter Output |  | The video outputs are configured as emitter–followers with a driving capability of about 15 mA each.<br>The dc voltage at these three emitters is set to 1.2 V (black level).<br>The dc current through the output stage is determined by the emitter resistors (typically 330 Ω). |
| 16<br>18<br>21 | B Clamp Capacitor<br>G Clamp Capacitor<br>R Clamp Capacitor |  | A 100 nF capacitor is connected to each of these pins.<br>The capacitor is used for video output dc restoration. |
| 17 | Video $V_{CC}$ | | Connect to 8.0 V dc supply, ±5%. This $V_{CC}$ is for the video output stage. It is internally connected to the collectors of the output transistors. |
| 20 | 5.0 $V_{ref}$ (V5) |  | 5.0 V regulator. Minimum 10 µF capacitor is required for noise filtering and compensation. It can source up to 20 mA but not sink current. Output impedance is ≈ 10 Ω. Recommended for use as a voltage reference only. |

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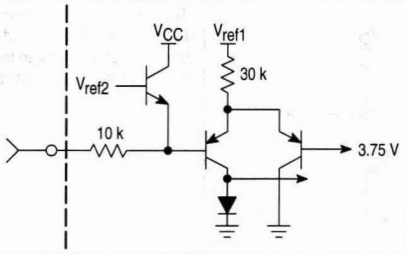
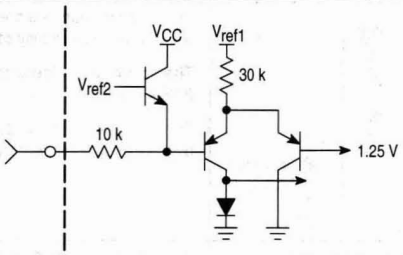
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Name | Equivalent Internal Circuit | Description |
|---|---|---|---|
| 23 | Clamp |  | This pin is used for video clamping.<br>The threshold clamping level is 3.75 V. |
| 24 | Blank |  | This pin is used for video blanking.<br>The threshold blanking level is 1.25 V. |

## FUNCTIONAL DESCRIPTION

The MC13282A is composed of three video amplifiers, clamping and blanking circuitry with contrast and subcontrast controls and OSD interface. Each video amplifier is designed to have a –3.0 dB bandwidth of 100 MHz with a gain of up to about 5.6 V/V, or 15 dB.

### Video Input

The video input stages are high impedance and designed to accept a maximum signal of 1.0 Vpp with 75 Ω termination (typically) provided externally. During the clamping period, a current is provided to the input capacitor by the clamping circuit which brings the input to a proper dc level (nominal 2.0 V). The blanking and clamping signals are to be provided externally, with their thresholds sitting at 1.25 V and 3.75 V, respectively.

### Video Output

The video output stages are configured as emitter–followers, with a driving capability of about 15 mA for each channel. The dc voltage at these three emitters is set to 1.2 V (black level). The dc current through each output stage is determined by the emitter resistor (typically 330 Ω).

### Contrast Control

The contrast control varies the gain of three video amplifiers from a minimum of 0.3 V/V to a maximum of 5.6 V/V when all subcontrast levels are set to 5.0 V.

### Subcontrast Control

Each subcontrast control provides a maximum of 26 dB attenuation on each video amplifier separately.

### OSD Interface

The three OSD inputs are TTL compatible and have a typical bandwidth of 50 MHz. A fast commutate pin is provided to select either the video or the OSD inputs as the source for the outputs. OSD contrast control is also provided to set the amount of gain required when OSD inputs are selected.

### Clamp Pulse Input

The clamping pulse is provided externally, and the pulse width must be no less than 500 ns.

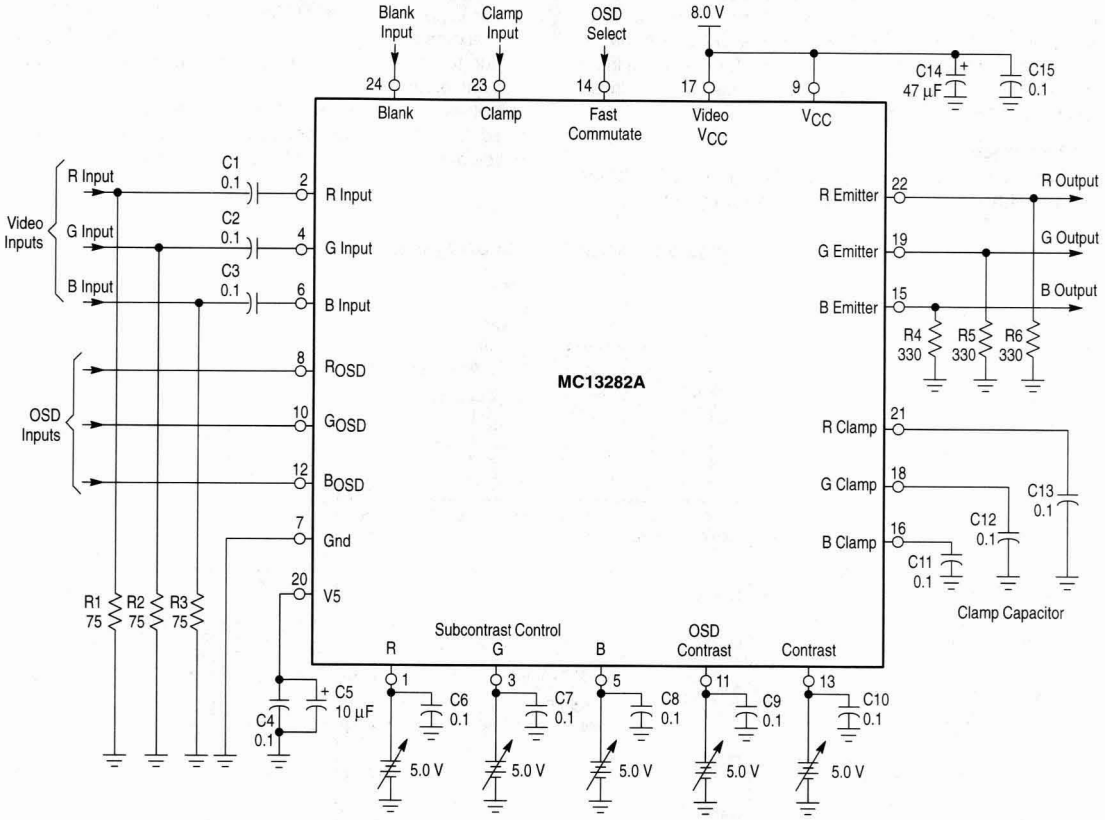
### Blank Pulse Input

The blanking pulse is used to blank the video signal during the horizontal sync period, or used as a control pin for video mute function.

### Power Supplies

$V_{CC}$ and Video $V_{CC}$ supplies are to be 8.0 V ±5%.

**Figure 2. Test Circuit**




## APPLICATION INFORMATION

### PCB Layout

Care should be taken in the PCB layout to minimize the noise effects. The most sensitive pins are $V_{CC}$ (9), Video $V_{CC}$ (17), V5 (20), Clamp (16, 18, 21). It is strongly recommended to make a ground plane and connect $V_{CC}$/Video $V_{CC}$ and ground traces to the power supply directly. Separate power supply traces, should be used for $V_{CC}$ and Video $V_{CC}$ and decoupling capacitors should be connected as close as possible to the device. Multi–layer ceramic and tantalum capacitors are recommended. Pin 20 (V5) is designed as a 5.0 V voltage reference for contrast, RGB subcontrast and OSD contrast controls, so the same precaution for $V_{CC}$ should be also applied at this pin. The Clamp capacitors at Pins 16,18 and 21 should be connected to ground close to IC's ground Pin 7 or power supply ground. The copper trace of the video signal inputs and outputs should be as short as possible and separated by ground traces to avoid any RGB cross–interference. A double sided PCB should be used to optimize the device's performance.

### RGB Input and Output

The RGB output stages are designed as emitter–followers to drive the CRT driver circuitry directly. The emitter resistors used is 330 Ω (typically) and the driving current is 15 mA maximum for each channel. The loading impedance connected to the output stages should be greater than 330 Ω and less than 5.0 pF for optimum performance (e.g., rise/fall time, bandwidth, etc.). Decreasing the resistive load will reduce the rise/fall time by increasing the driving current, but the output stage may be damaged due to increasing power dissipation at the same time. The frequency response is affected by the loading capacitance. The typical value is 3.0 to 5.0 pF. Figure 4 shows a typical interface with a video output driver. For a high resolution color monitor application, it is recommended to use coaxial cable or shielded cable for input signal connections.

### Clamp and Blank Input

The clamp input is normally (except for Sync–on–Green) connected to a positive horizontal sync pulse, and has a threshold level of 3.75 V. It is used as a timing reference for the dc restoration process, so it cannot be left open. If Sync–on–Green timing mode is used, the clamping pulse should be located at horizontal back porch period instead of horizontal sync tip. Otherwise, the black level will be clamped at an incorrect voltage.

The blank input is used as a video mute, or horizontal blanking control, and is normally connected to a blanking

pulse generated from the flyback or from an MCU. The threshold level of 1.25 V. The blanking pulse width should be equal to the flyback retrace period to make sure that the video signal is blanked properly during retrace. It is necessary to limit the amplitude, and avoid any negative undershoots if the flyback pulse is used. This Blanking input pin cannot accept a negative voltage. This pin should be grounded if it is not used.

**OSD interface**

Figure 3 show a typical application with an OSD device (MC141540). The MC141540 OSD and FC outputs are TTL compatible, and therefore interface directly with MC13282A. Level shifting circuitry is not needed. The MC141540 is a digital device, controlled by an MCU. Therefore, separate power supply runs to the MC141540 and to the MC13282A are recommended. Care should be taken in the PC board layout to prevent digital noise from entering the analog portions of MC13282A.

Normally the OSD switching is done during the active video time. It is recommended that the Fast Commutate pin not be activated during the horizontal sync time.

**Figure 3. Interfacing with OSD Device**

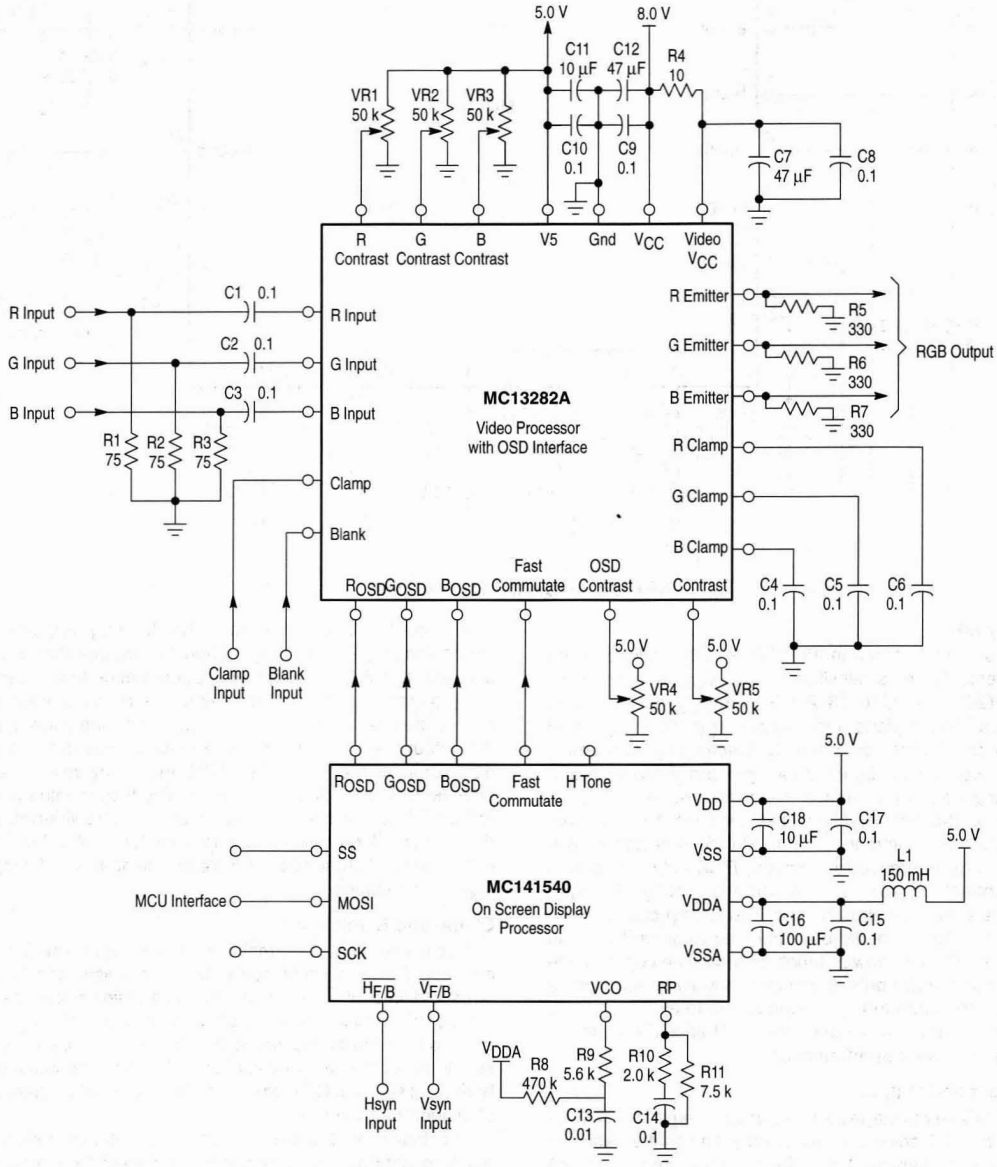
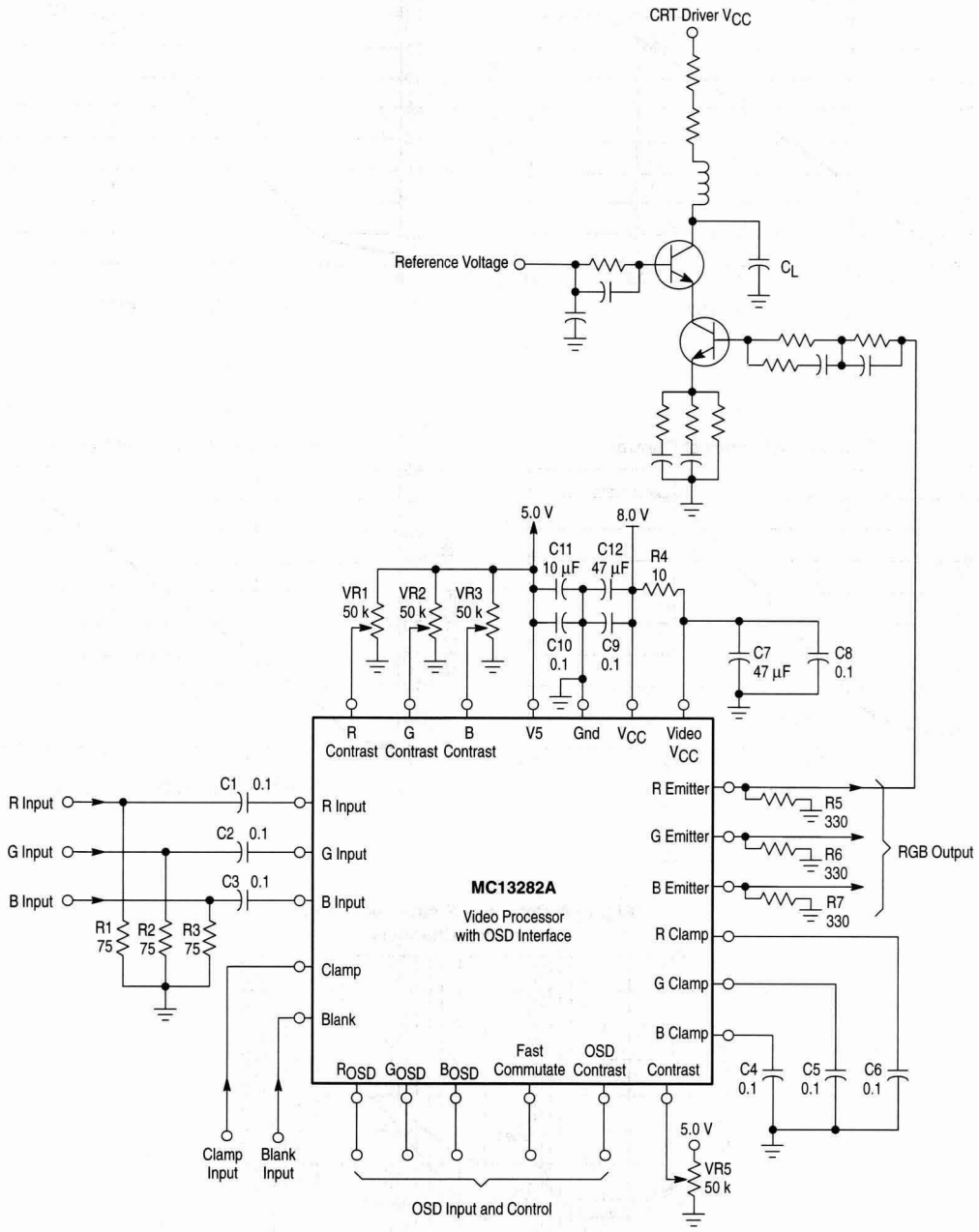


**Figure 4. Interfacing with Video Output Drivers**




9

**Figure 5. RGB In/Out Linearity**

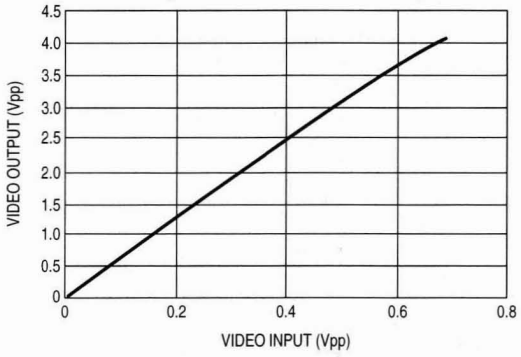



**Figure 6. Color Contrast**

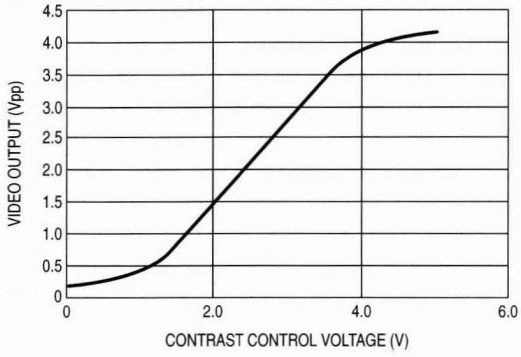



**Figure 7. Subcontrast Control**

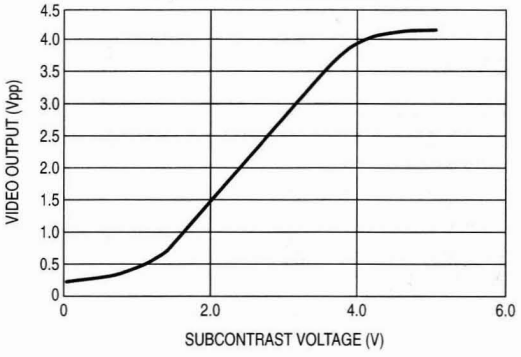



**Figure 8. OSD Contrast Control**

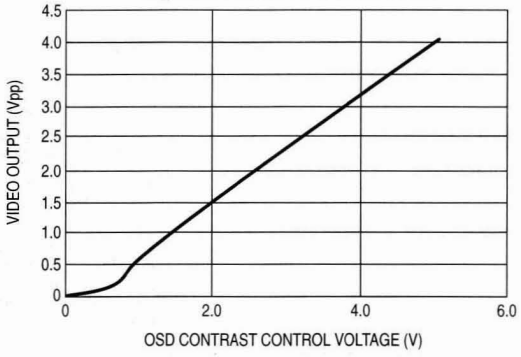



**Figure 9. Crosstalk From Green to Red and Blue Channels**

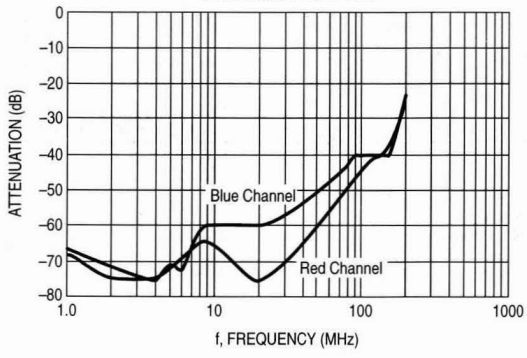
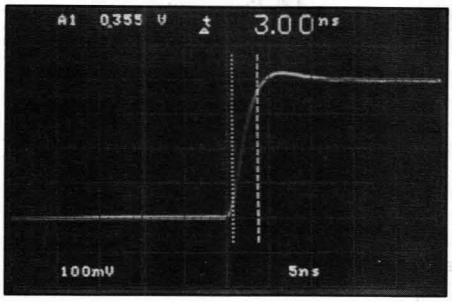
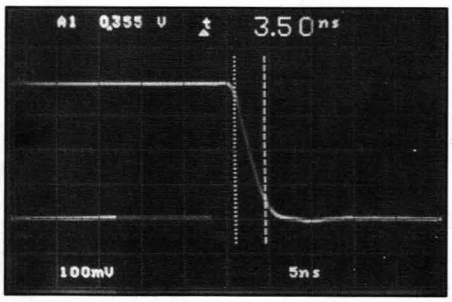


**Figure 10. Rise Time**




100 mV/DIV
5.0 ns/DIV
10x PROBE

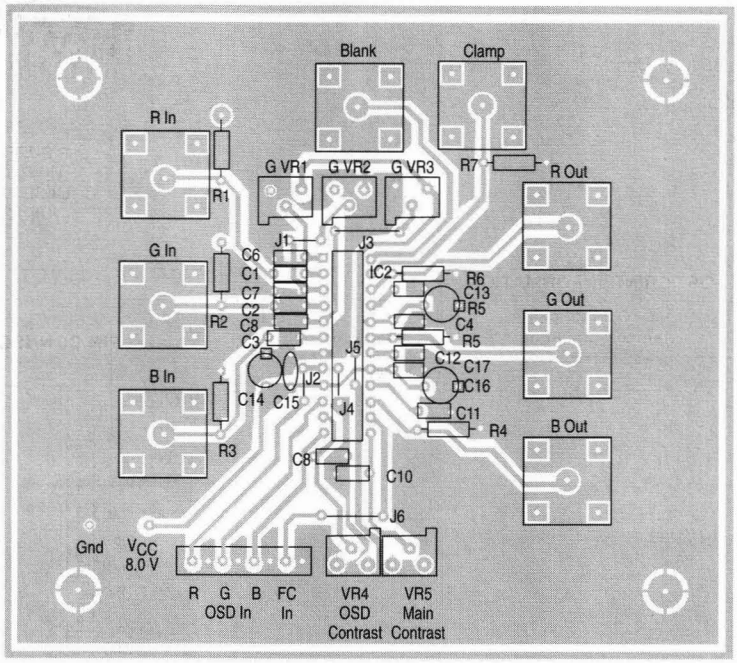
**Figure 11. Fall Time**




100 mV/DIV
5.0 ns/DIV
10x PROBE

**NOTE:** Recommended to use a double sided PCB without any socket for rise/fall time measurements, using an input pulse with 1.5 ns rise/fall time and an active probe with 1.7 pF capacitance loading.

**Figure 12. Single Sided PCB Layout (Component Side)**




**NOTE:** J = Jumper

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MOTOROLA

# MC13283

*Product Preview*

## 130 MHz Video Processor with OSD Interface

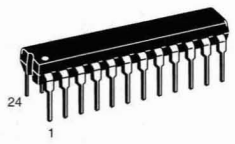
The MC13283 is a three channel wideband amplifier designed for use as a video pre–amp in high resolution RGB color monitors.

*Features:*

- 4.0 Vpp Output with 130 MHz Bandwidth
- 2.6 ns Rise and 3.2 ns Fall Time
- Subcontrast Control for Each Channel
- Blanking and Clamping Inputs
- Contrast Control
- OSD Interface with 85 MHz Bandwidth
- OSD Contrast Control
- Package: NDIP–24

**130 MHz VIDEO PROCESSOR WITH OSD INTERFACE**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 724
(NDIP–24)

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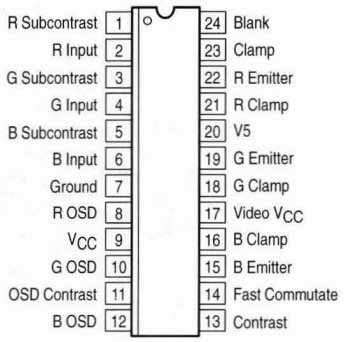
**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC13283P | $T_A$ = 0° to +70°C | Plastic DIP |

**PIN CONNECTIONS**




(Top View)

MOTOROLA

# MC34119

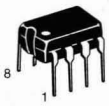
# Low Power Audio Amplifier

The MC34119 is a low power audio amplifier intergrated circuit intended (primarily) for telephone applications, such as in speakerphones. It provides differential speaker outputs to maximize output swing at low supply voltages (2.0 V minimum). Coupling capacitors to the speaker are not required. Open loop gain is 80 dB, and the closed loop gain is set with two external resistors. A Chip Disable pin permits powering down and/or muting the input signal. The MC34119 is available in standard 8–pin DIP, SOIC package, and TSSOP package.

- Wide Operating Supply Voltage Range (2.0 V to 16 V), Allows Telephone Line Powered Applications
- Low Quiescent Supply Current (2.7 mA Typ) for Battery Powered Applications
- Chip Disable Input to Power Down the IC
- Low Power–Down Quiescent Current (65 µA Typ)
- Drives a Wide Range of Speaker Loads (8.0 Ω and Up)
- Output Power Exceeds 250 mW with 32 Ω Speaker
- Low Total Harmonic Distortion (0.5% Typ)
- Gain Adjustable from <0 dB to >46 dB for Voice Band
- Requires Few External Components

**LOW POWER AUDIO AMPLIFIER**

**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

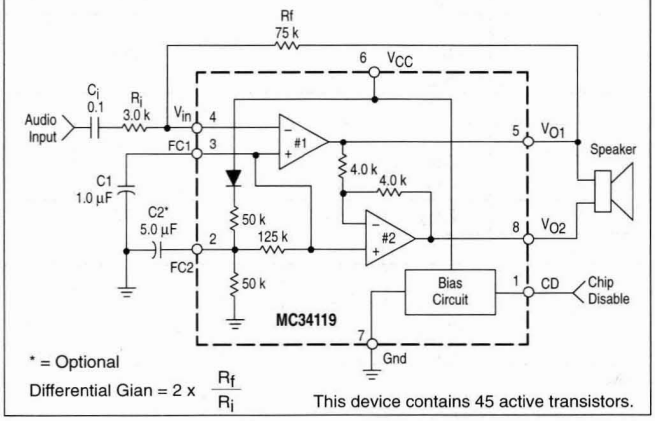
**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948J
(TSSOP)

**MAXIMUM RATINGS**

| Rating | Value | Unit |
|---|---|---|
| Supply Voltage | –1.0 to +18 | Vdc |
| Maximum Output Current at $V_{O1}$, $V_{O2}$ | ±250 | mA |
| Maximum Voltage @ $V_{in}$, FC1, FC2, CD<br>Applied Output Voltage to $V_{O1}$, $V_{O2}$ when disabled | –1.0, $V_{CC}$ + 1.0<br>–1.0, $V_{CC}$ + 1.0 | Vdc |
| Junction Temperature | –55, +140 | °C |

**NOTE:** ESD data available upon request.

**Block Diagram and Simplified Application**

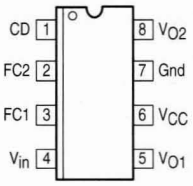



* = Optional

Differential Gian = $2 \times \frac{R_f}{R_i}$

This device contains 45 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC34119P | $T_A$ = –20° to +70°C | Plastic DIP |
| MC34119D | | SO–8 |
| MC34119DTB | | TSSOP |

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## RECOMMENDED OPERATING CONDITIONS

| Characteristics | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Supply Voltage<br>Voltage @ CD (Pin 1) | $V_{CC}$<br>$V_{CD}$ | +2.0<br>0 | +16<br>$V_{CC}$ | Vdc<br>Vdc |
| Load Impedance | $R_L$ | 8.0 | – | Ω |
| Peak Load Current | $I_L$ | – | ±200 | mA |
| Differential Gain (5.0 kHz Bandwidth) | AVD | 0 | 46 | dB |
| Ambient Temperature | $T_A$ | –20 | +70 | °C |

## ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **AMPLIFIERS (AC CHARACTERISTICS)** | | | | | |
| AC Input Resistance (@ $V_{In}$) | $r_i$ | – | >30 | – | MΩ |
| Open Loop Gain (Amplifier #1, f < 100 Hz) | $A_{VOL1}$ | 80 | – | – | dB |
| Closed Loop Gain (Amplifier #2, $V_{CC}$ = 6.0 V, f = 1.0 kHz, $R_L$ = 32 Ω) | $A_{V2}$ | –0.35 | 0 | +0.35 | dB |
| Gain Bandwidth Product | GBW | – | 1.5 | – | MHz |
| Output Power;<br>$V_{CC}$ = 3.0 V, $R_L$ = 16 Ω, THD ≤ 10%<br>$V_{CC}$ = 6.0 V, $R_L$ = 32 Ω, THD ≤ 10%<br>$V_{CC}$ = 12 V, $R_L$ = 100 Ω, THD ≤ 10% | <br>$P_{Out3}$<br>$P_{Out6}$<br>$P_{Out12}$ | <br>55<br>250<br>400 | <br>–<br>–<br>– | <br>–<br>–<br>– | mW |
| Total Harmonic Distortion (f = 1.0 kHz)<br>($V_{CC}$ = 6.0 V, $R_L$ = 32 Ω, $P_{out}$ = 125 mW)<br>($V_{CC}$ ≥ 3.0 V, $R_L$ = 8.0 Ω, $P_{out}$ = 20 mW)<br>($V_{CC}$ ≥ 12 V, $R_L$ = 32 Ω, $P_{out}$ = 200 mW) | THD | <br>–<br>–<br>– | <br>0.5<br>0.5<br>0.6 | <br>1.0<br>–<br>– | % |
| Power Supply Rejection ($V_{CC}$ = 6.0 V, $\Delta V_{CC}$ = 3.0 V)<br>(C1 = ∞, C2 = 0.01 µF)<br>(C1 = 0.1 µF, C2 = 0, f = 1.0 kHz)<br>(C1 = 1.0 µF, C2 = 5.0 µF, f = 1.0 kHz) | PSRR | <br>50<br>–<br>– | <br>–<br>12<br>52 | <br>–<br>–<br>– | dB |
| Differential Muting ($V_{CC}$ = 6.0 V, 1.0 kHz ≤ f ≤ 20 kHz, CD = 2.0 V) | GMT | – | >70 | – | dB |
| **AMPLIFIERS (DC CHARACTERISTICS)** | | | | | |
| Output DC Level @ $V_{O1}$, $V_{O2}$, $V_{CC}$ = 3.0 V, $R_L$ = 16 ($R_f$ = 75 k)<br>$V_{CC}$ = 6.0 V<br>$V_{CC}$ = 12 V | $V_{O(3)}$<br>$V_{O(6)}$<br>$V_{O(12)}$ | 1.0<br>–<br>– | 1.15<br>2.65<br>5.65 | 1.25<br>–<br>– | Vdc |
| Output Level<br>High ($I_{out}$ = –75 mA, 2.0 V ≤ $V_{CC}$ ≤ 16 V)<br>Low ($I_{out}$ = 75 mA, 2.0 V ≤ $V_{CC}$ ≤ 16 V) | <br>$V_{OH}$<br>$V_{OL}$ | <br>–<br>– | <br>$V_{CC}$ – 1.0<br>0.16 | <br>–<br>– | Vdc |
| Output DC Offset Voltage ($V_{O1}$–$V_{O2}$)<br>($V_{CC}$ = 6.0 V, $R_f$ = 75 kΩ, $R_L$ = 32 Ω) | $\Delta V_O$ | <br>–30 | <br>0 | <br>+30 | mV |
| Input Bias Current @ $V_{in}$ ($V_{CC}$ = 6.0 V) | $I_{IB}$ | – | –100 | –200 | nA |
| Equivalent Resistance<br>@ FC1 ($V_{CC}$ = 6.0 V)<br>@ FC2 ($V_{CC}$ = 6.0 V) | <br>$R_{FC1}$<br>$R_{FC2}$ | <br>100<br>18 | <br>150<br>25 | <br>220<br>40 | kΩ |
| **CHIP DISABLE** (Pin 1) | | | | | |
| Input Voltage<br>Low<br>High | <br>$V_{IL}$<br>$V_{IH}$ | <br>–<br>2.0 | <br>–<br>– | <br>0.8<br>– | Vdc |
| Input Resistance ($V_{CC}$ = $V_{CD}$ = 16 V) | $R_{CD}$ | 50 | 90 | 175 | kΩ |
| **POWER SUPPLY** | | | | | |
| Power Supply Current<br>($V_{CC}$ = 3.0 V, $R_L$ = ∞, CD = 0.8 V)<br>($V_{CC}$= 16 V, $R_L$ = ∞, CD = 0.8 V)<br>($V_{CC}$ = 3.0 V, $R_L$ = ∞, CD = 2.0 V) | <br>$I_{CC3}$<br>$I_{CC16}$<br>$I_{CCD}$ | <br>–<br>–<br>– | <br>2.7<br>3.3<br>65 | <br>4.0<br>5.0<br>100 | <br>mA<br>mA<br>µA |

**NOTE:** Currents into a pin are positive, currents out of a pin are negative.

## PIN FUNCTION DESCRIPTION

| Symbol | Pin | Description |
|---|---|---|
| CD | 1 | Chip Disable – Digital input. A Logic "0" (<0.8 V) sets normal operation. A logic "1" (≥2.0 V) sets the power down mode. Input impedance is nominally 90 kΩ . |
| FC2 | 2 | A capacitor at this pin increases power supply rejection, and affects turn–on time. This pin can be left open if the capacitor at FC1 is sufficient. |
| FC1 | 3 | Analog ground for the amplifiers. A 1.0 μF capacitor at this pin (with a 5.0 μF capacitor at Pin 2) provides (typically) 52 dB of power supply rejection. Turn–on time of the circuit is affected by the capacitor on this pin. This pin can be used as an alternate input. |
| $V_{in}$ | 4 | Amplifier input. The input capacitor and resistor set low frequency rolloff and input impedance. The feedback resistor is connected to this pin and $V_{O1}$. |
| $V_{O1}$ | 5 | Amplifier Output #1. The dc level is ≈ ($V_{CC}$ – 0.7 V)/2. |
| $V_{CC}$ | 6 | DC supply voltage (+2.0 V to +16 V) is applied to this pin. |
| GND | 7 | Ground pin for the entire circuit. |
| $V_{O2}$ | 8 | Amplifier Output #2. This signal is equal in amplitude, but 180° out–of–phase with that at $V_{O1}$. The dc level is ≈ ($V_{CC}$ – 0.7 V)/2. |

## TYPICAL TEMPERATURE PERFORMANCE (–20° C < $T_A$ < +70°C)

| Function | Typical Change | Units |
|---|---|---|
| Input Bias Current (@ $V_{in}$) | ±40 | pA/°C |
| Total Harmonic Distortion ($V_{CC}$ = 6.0 V, $R_L$ = 32 Ω. $P_{out}$ = 125 mW, f = 1.0 kHz) | +0.003 | %/°C |
| Power Supply Current<br>($V_{CC}$ = 3.0 V, $R_L$ = ∞, CD = 0 V)<br>($V_{CC}$ = 3.0 V, $R_L$ = ∞, CD = 2.0 V) | <br>–2.5<br>–0.03 | μA/°C |

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## DESIGN GUIDELINES

### General

The MC34119 is a low power audio amplifier capable of low voltage operation ($V_{CC}$ = 2.0 V minimum) such as that encountered in line–powered speakerphones. The circuit provides a differential output ($V_{O1}$–$V_{O2}$) to the speaker to maximize the available voltage swing at low voltages. The differential gain is set by two external resistors. Pins FC1 and FC2 allow controlling the amount of power supply and noise rejection, as well as providing alternate inputs to the amplifiers. The CD pin permits powering down the IC for muting purposes and to conserve power.

### Amplifiers

Referring to the block diagram, the internal configuration consists of two identical operational amplifiers. Amplifier #1 has an open loop gain of ≥80 dB (at f ≤ 100 Hz), and the closed loop gain is set by external resistor $R_f$ and $R_i$. The amplifier is unity gain stable, and has a unity gain frequency of approximately 1.5 MHz. In order to adequately cover the telephone voice band (300 Hz to 3400 Hz), a maximum closed loop gain of 46 is recommended. Amplifier #2 is internally set to a gain of – 1.0 (0 dB).

The outputs of both amplifiers are capable of sourcing and sinking a peak current of 200 mA. The outputs can typically swing to within ≈0.4 V above ground, and to within ≈1.3 V below $V_{CC}$, at the maximum current. See Figures 18 and 19 for $V_{OH}$ and $V_{OL}$ curves.

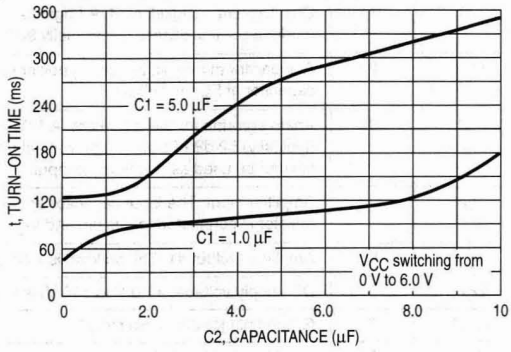
The output dc offset voltage ($V_{O1}$–$V_{O2}$) is primarily a function of the feedback resistor ($R_f$), and secondarily due to the amplifiers' input offset voltages. The input offset voltage of the two amplifiers will generally be similar for a particular IC, and therefore nearly cancel each other at the outputs. Amplifier #1's bias current, however, flows out of $V_{in}$ (Pin 4) and through $R_f$, forcing $V_{O1}$ to shift negative by an amount equal to [$R_f \times I_{IB}$]. $V_{O2}$ is shifted positive an equal amount. The output offset voltage, specified in the Electrical Characteristics, is measured with the feedback resistor shown in the Typical Application Circuit, and therefore takes into account the bias current as well as internal offset voltages of the amplifiers. The bias current is constant with respect to $V_{CC}$.

### FC1 and FC2

Power supply rejection is provided by the capacitors (C1 and C2 in the Typical Application Circuit) at FC1 and FC2. C2 is somewhat dominant at low frequencies, while C1 is dominant at high frequencies, as shown in the graphs of Figures 4 to 7. The required values of C1 and C2 depend on the conditions of each application. A line powered speakerphone, for example, will require more filtering than a circuit powered by a well regulated power supply. The amount of rejection is a function of the capacitors, and the equivalent impedance looking into FC1 and FC2 (listed in the Electrical Characteristics as $R_{FC1}$ and $R_{FC2}$).

In addition to providing filtering, C1 and C2 also affect the turn–on time of the circuit at power–up, since the two capacitors must charge up through the internal 50 k and 125 kΩ resistors. The graph of Figure 1 indicates the turn–on time upon application of $V_{CC}$ of +6.0 V. The turn–on time is ≈60% longer for $V_{CC}$ = 3.0 V, and ≈20% less for $V_{CC}$ = 9.0 V. Turn–off time is <10 µs upon removal of $V_{CC}$.

**Figure 1. Turn–On Time versus C1, C2 at Power–On**




### Chip Disable

The Chip Disable (Pin 1) can be used to power down the IC to conserve power, or for muting, or both. When at a Logic "0" (0 V to 0.8 V), the MC34119 is enabled for normal operation. When Pin 1 is at a Logic "1" (2.0 V to $V_{CC}$ V), the IC is disabled. If Pin 1 is open, that is equivalent to a Logic "0," although good design practice dictates that an input should never be left open. Input impedance at Pin 1 is a nominal 90 kΩ. The power supply current (when disabled) is shown in Figure 15.

Muting, defined as the change in differential gain from normal operation to muted operation, is in excess of 70 dB. The turn–off time of the audio output, from the application of the CD signal, is <2.0 µs, and turn on–time is 12 ms–15 ms. Both times are independent of C1, C2, and $V_{CC}$.

When the MC34119 is disabled, the voltages at FC1 and FC2 do not change as they are powered from $V_{CC}$. The outputs, $V_{O1}$ and $V_{O2}$, change to a high impedance condition, removing the signal from the speaker. If signals from other sources are to be applied to the outputs (while disabled), they must be within the range of $V_{CC}$ and Ground.

### Power Dissipation

Figures 8 to 10 indicate the device dissipation (within the IC) for various combinations of $V_{CC}$, $R_L$, and load power. The maximum power which can safely be dissipated within the MC34119 is found from the following equation:

$$P_D = (140°C - T_A)/\theta_{JA}$$

where $T_A$ is the ambient temperature; and $\theta_{JA}$ is the package thermal resistance (100°C/W for the standard DIP package, and 180°C/W for the surface mount package.)

The power dissipated within the MC34119, in a given application, is found from the following equation:

$$P_D = (V_{CC} \times I_{CC}) + (I_{RMS} \times V_{CC}) - (R_L \times I_{RMS}^2)$$

where $I_{CC}$ is obtained from Figure 15; and $I_{RMS}$ is the RMS current at the load; and $R_L$ is the load resistance.

Figures 8 to 10, along with Figures 11 to 13 (distortion curves), and a peak working load current of ±200 mA, define the operating range for the MC34119. The operating range is further defined in terms of allowable load power in Figure 14 for loads of 8.0 Ω, 16 Ω and 32 Ω. The left (ascending) portion

of each of the three curves is defined by the power level at which 10% distortion occurs. The center flat portion of each curve is defined by the maximum output current capability of the MC34119. The right (descending) portion of each curve is defined by the maximum internal power dissipation of the IC at 25°C. At higher ambient temperatures, the maximum load power must be reduced according to the above equations. Operating the device beyond the current and junction temperature limits will degrade long term reliability.

**Layout Considerations**

Normally a snubber is not needed at the output of the MC34119, unlike many other audio amplifiers. However, the PC board layout, stray capacitances, and the manner in which the speaker wires are configured, may dictate otherwise. Generally, the speaker wires should be twisted tightly, and not more than a few inches in length.

**Figure 2. Amplifier #1 Open Loop Gain and Phase**

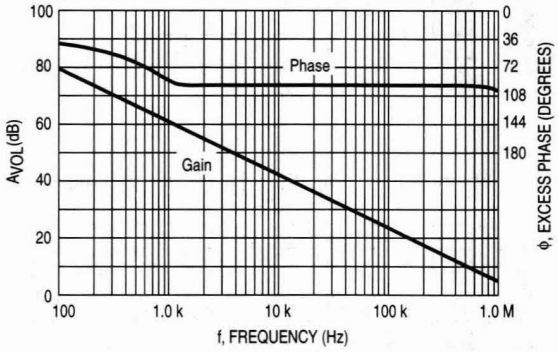



**Figure 3. Differential Gain versus Frequency**

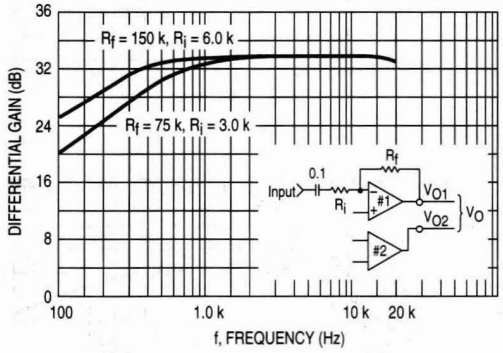



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**Figure 4. Power Supply Rejection versus Frequency (C2 = 10 μF)**

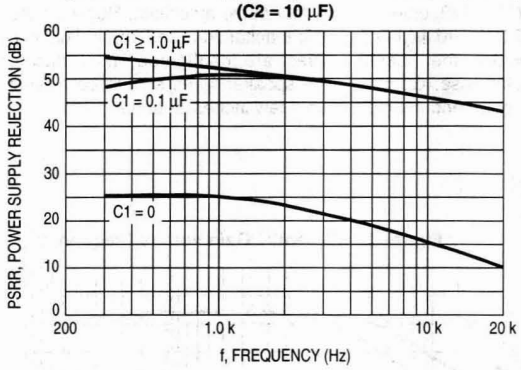


**Figure 5. Power Supply Rejection versus Frequency (C2 = 5.0 μF)**

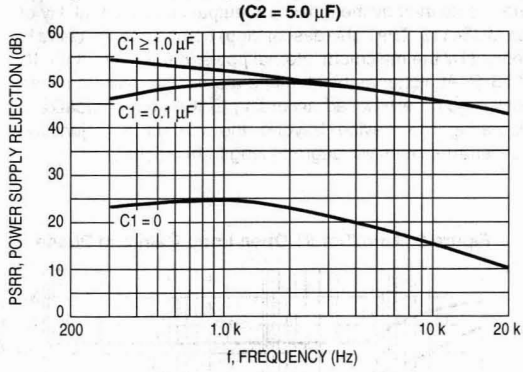


**Figure 6. Power Supply Rejection versus Frequency (C2 = 1.0 μF)**

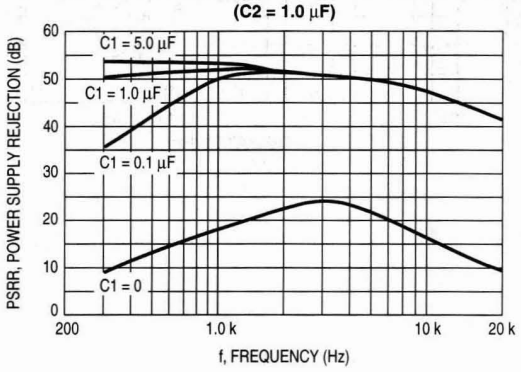


**Figure 7. Power Supply Rejection versus Frequency (C2 = 0)**

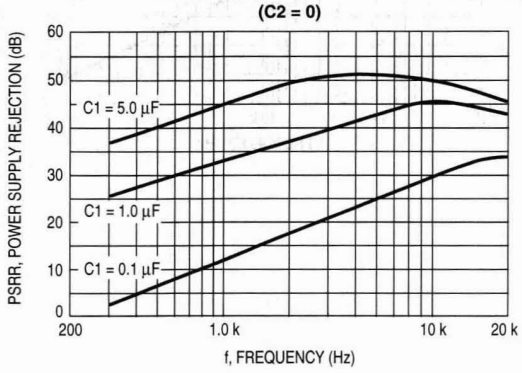


**Figure 8. Device Dissipation, 8.0 Ω Load**

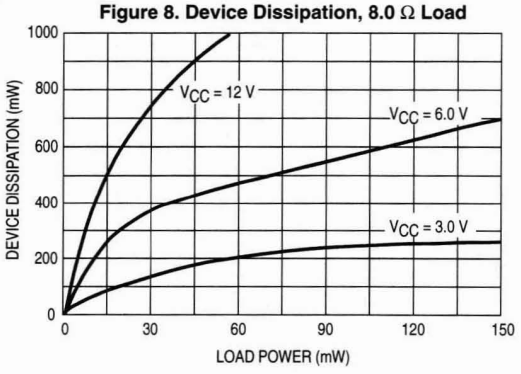


**Figure 9. Device Dissipation, 16 Ω Load**

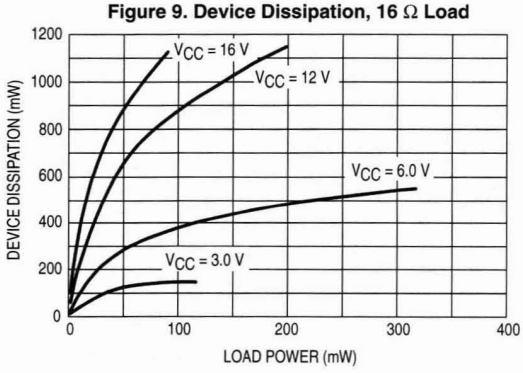


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**Figure 10. Device Dissipation, 32 Ω Load**

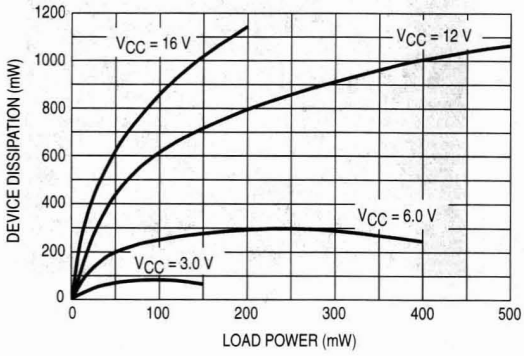


**Figure 11. Distortion versus Power**
**(f = 1.0 kHz, AVD = 34 dB)**

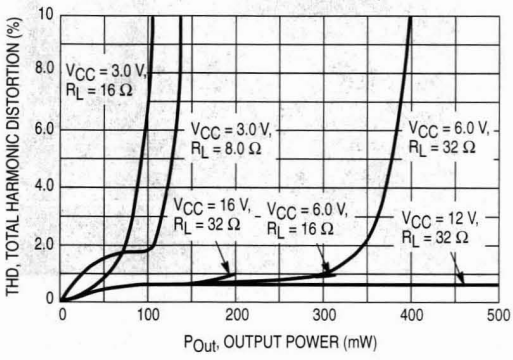


**Figure 12. Distortion versus Power**
**(f = 3.0 kHz, AVD = 34 dB)**

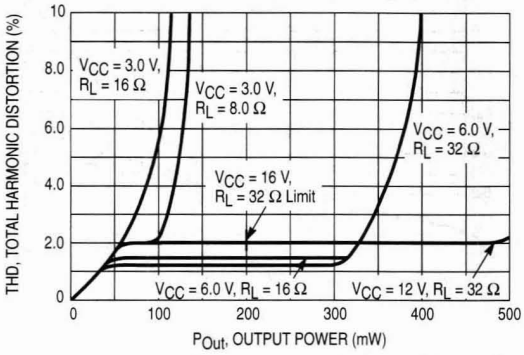


**Figure 13. Distortion versus Power**
**(f = 1, 3.0 kHz, AVD = 12 dB)**

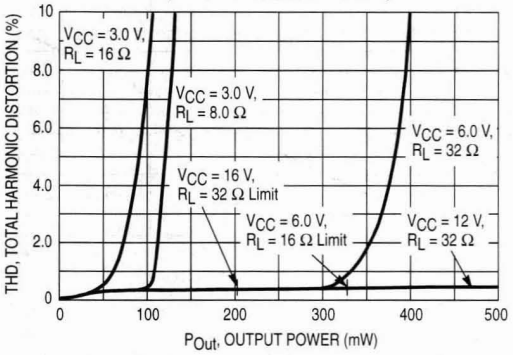


**Figure 14. Maximum Allowable Load Power**

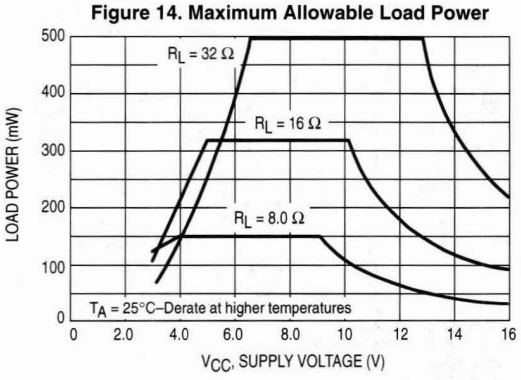


**Figure 15. Power Supply Current**

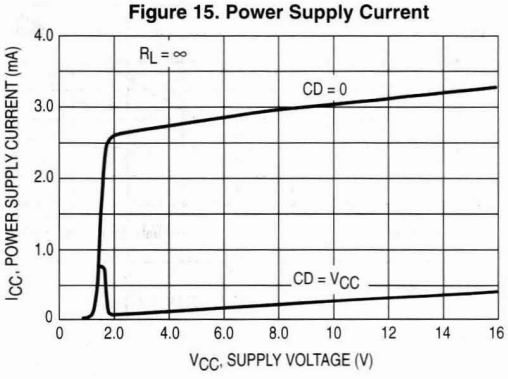


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**Figure 16. Small Signal Response**

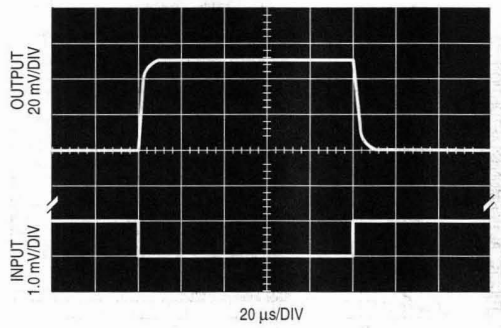



**Figure 17. Large Signal Response**

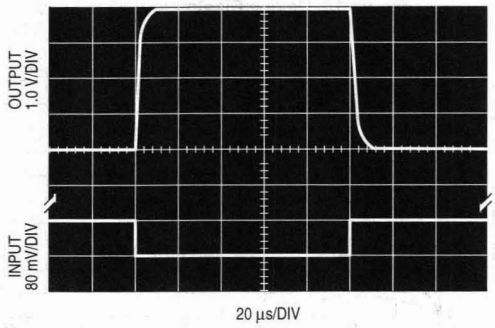



**Figure 18. $V_{CC}-V_{OH}$ @ $V_{O1}$, $V_{O2}$ versus Load Current**

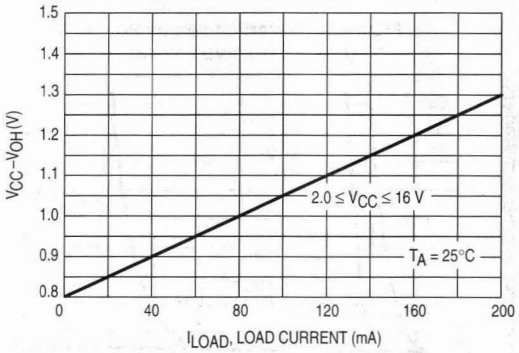



**Figure 19. $V_{OL}$ @ $V_{O1}$, $V_{O2}$ versus Load Current**

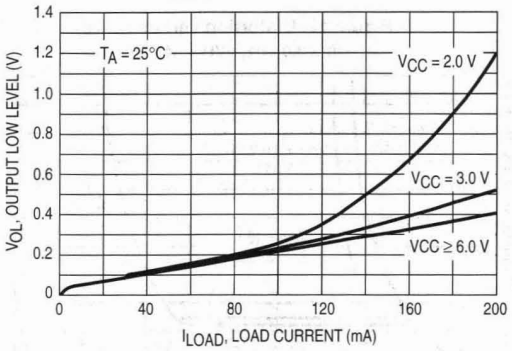



**Figure 20. Input Characteristics @ CD (Pin 1)**

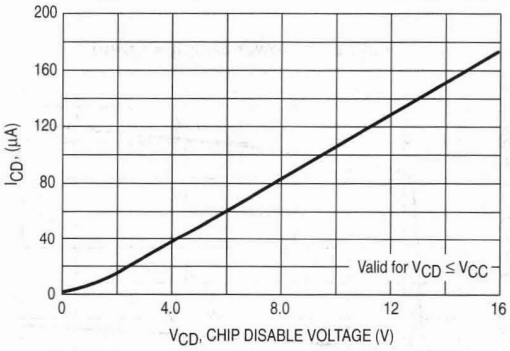
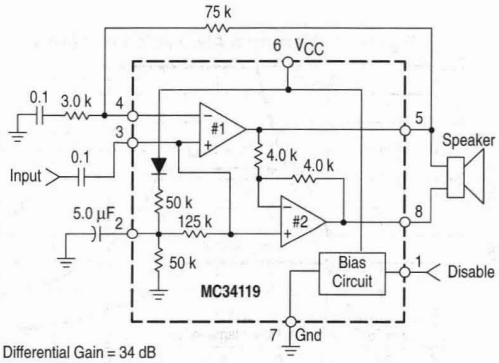



**Figure 21. Audio Amplifier with High Input Impedance**




Differential Gain = 34 dB
Frequency Response: See Figure 3
Input Impedance ≈ 125 kΩ
PSRR ≈ 50 dB

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**Figure 22. Audio Amplifier with Bass Suppression**

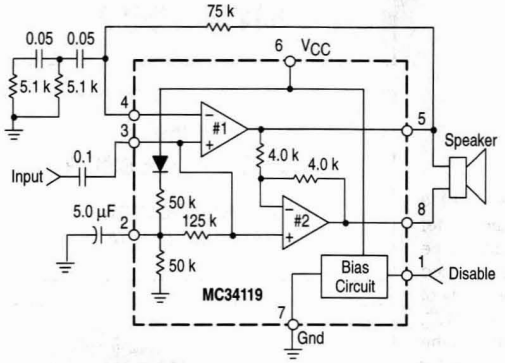



**Figure 23. Frequency Response of Figure 22**

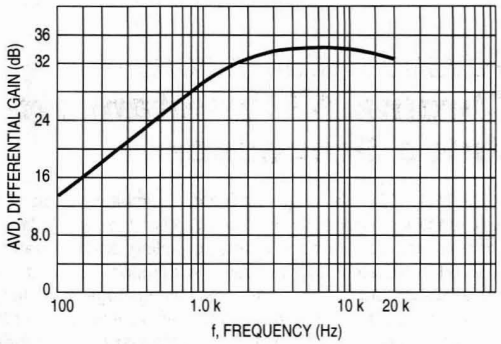



**Figure 24. Audio Amplifier with Bandpass**

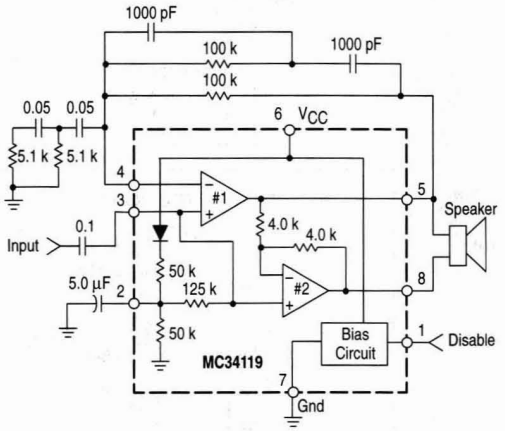



**Figure 25. Frequency Response of Figure 24**

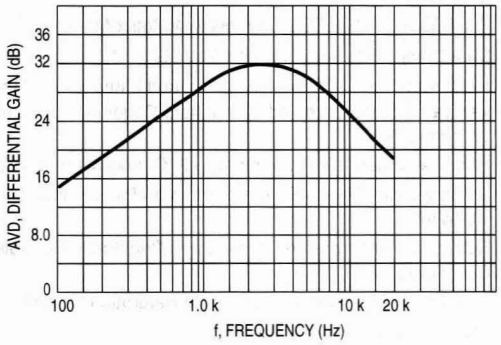
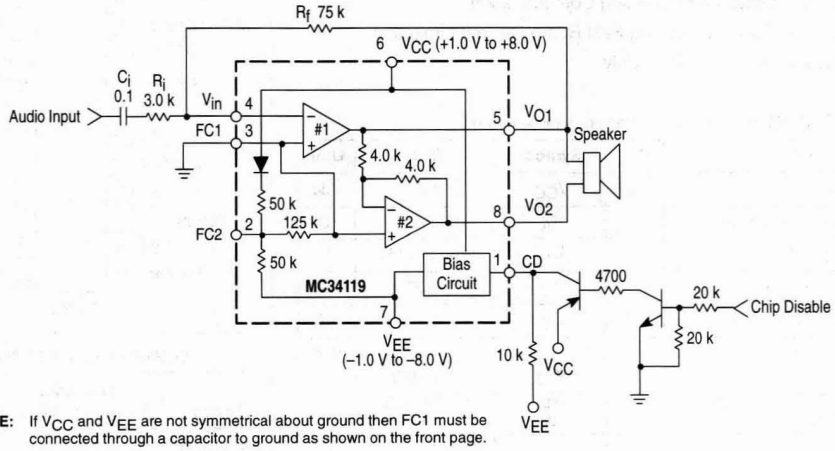



**Figure 26. Split Supply Operation**




**NOTE:** If $V_{CC}$ and $V_{EE}$ are not symmetrical about ground then FC1 must be connected through a capacitor to ground as shown on the front page.

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MOTOROLA

# MC44002
# MC44007

*Advance Information*

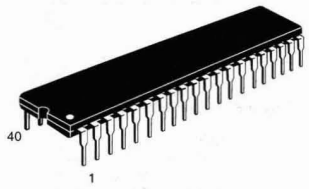
## Chroma 4 Multistandard Video Processor

**CHROMA 4 VIDEO PROCESSOR**

**SEMICONDUCTOR TECHNICAL DATA**

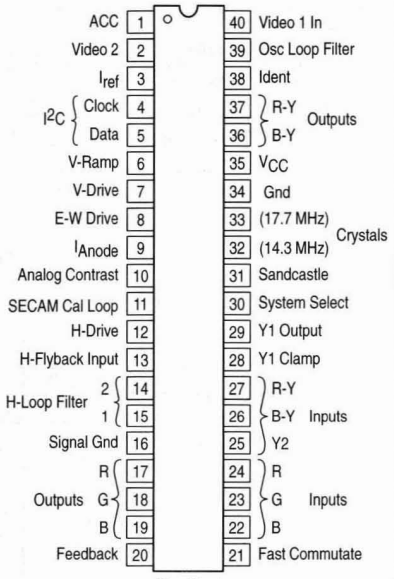
The MC44002/7 is a highly advanced circuit which performs most of the basic functions required for a color TV. All of its advanced features are under processor control via an $I^2C$ bus, enabling potentiometer controls to be removed completely. In this way the component count may be reduced dramatically, allowing significant cost savings together with the possibility of implementing sophisticated automatic test routines. Using the MC44002/7, TV manufacturers will be able to build a standard chassis for anywhere in the world. Additional features include 4 selectable matrix modes (primarily for NTSC), fast beam current limiting and 16:9 display.

- Operation from a Single 5.0 V Supply; Typical Current Consumption Only 120 mA
- Full PAL/SECAM/NTSC Capability (4 Matrix Modes)
- Dual Composite Video or S-VHS Inputs
- All Chroma/Luma Channel Filtering, and Luma Delay Line Are Integrated Using Sampled Data Filters Requiring No External Components
- Filters Automatically Commutate with Change of Standard
- Chroma Delay Line is Realized with a 16 Pin Companion Device, the MC44140
- RGB Drives Incorporate Contrast and Brightness Controls and Auto Gray Scale
- Switched RGB Inputs with Separate Saturation Control
- Auxiliary Y, R-Y, B-Y Inputs
- Line Timebase Featuring H-Phase Control, Time Constant and Switchable Phase Detector Gain
- Vertical Timebase Incorporating Vertical Geometry Corrections
- 16:9 Display Mode Capability
- E-W Parabola Drive Incorporating Horizontal Geometry Corrections
- Beam Current Monitor with Breathing Compensation
- Analog Contrast Control, Allowing Fast Beam Current Limitation
- MC44007 Decoders PAL/NTSC Only




**P SUFFIX**
PLASTIC PACKAGE
CASE 711

**PIN CONNECTIONS**




(Top View)

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Supply Voltage | 35 | $V_{CC}$ | 6.0 | Vdc |
| Operating Ambient Temperature | – | $T_A$ | 0 to + 70 | °C |
| Storage Temperature | – | $T_{stg}$ | – 65 to +150 | °C |
| Junction Temperature | – | $T_J$ | +150 | °C |
| Drive Output Sink Current | 12 | $I_{12}$ | 2.0 | mA |
| Applied Voltage Range: | | | | Vdc |
| Feedback | 20 | $V_{20}$ | 0 to +8.0 | |
| Anode Current | 9 | $V_9$ | – 2.0 to $V_{CC}$ | |
| All Other Pins | – | $V_i$ | 0 to $V_{CC}$ | |
| ESD | | | | V |

**NOTE:** ESD data available upon request.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44002P | $T_A$ = 0° to +70°C | Plastic DIP |
| MC44007P | | Plastic DIP |

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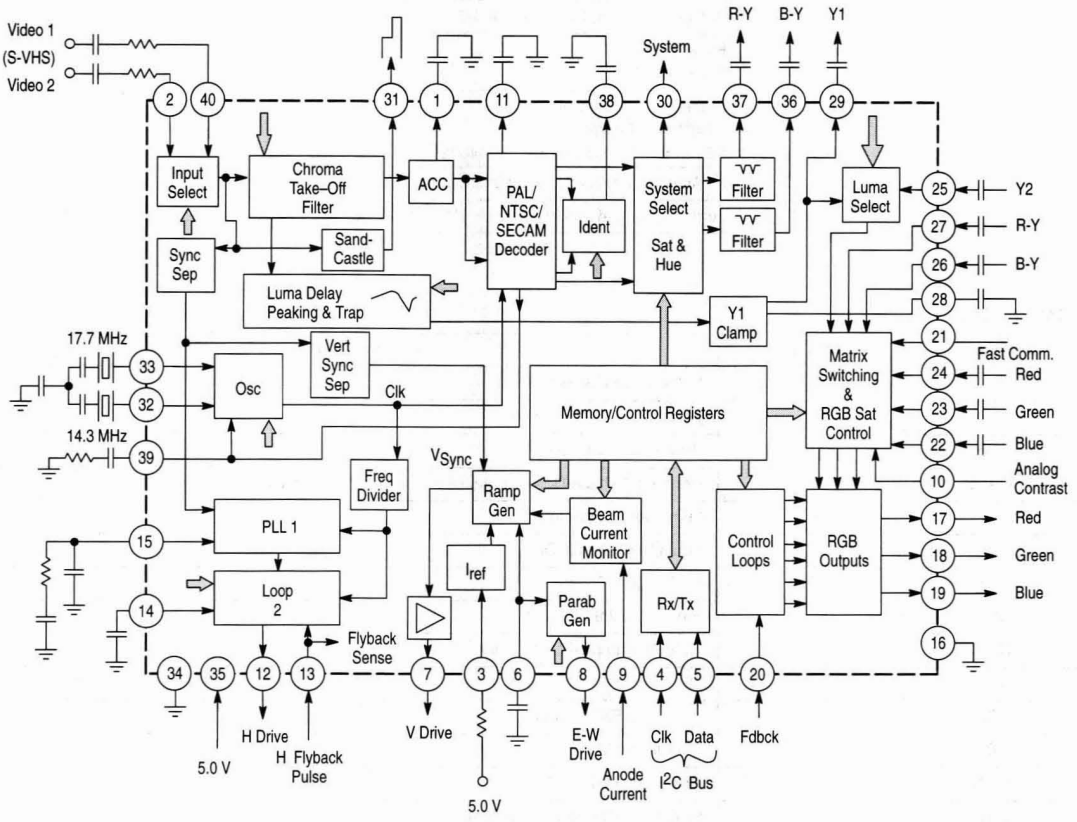
**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Symbol | Value | Unit |
|---|---|---|---|---|
| Human Body Model | – | – | ±2000 | |
| Machine Model | – | – | ±200 | |

**NOTE:** ESD data available upon request.

**Simplified Block Diagram**




This device contains 6,245 active transistors.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 Vdc, $I_3$ = 70 µA, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Voltage | 35 | 4.75 | 5.0 | 5.25 | V |
| Operating Current | 35 | 90 | 120 | 180 | mA |
| Reference Current, Input Voltage | 3 | 1.0 | 1.3 | 1.6 | V |
| Thermal Resistance, Junction–to–Ambient | – | – | 56 | – | °C/W |

**NOTES:** Composite Video Input Signal Level = 1.0 Vpp
Black-to-White = 0.Vpp7 , Syn-to-Black = 0.3 Vpp
PAL/NTSC = 75% color bars; Burst = 300 mVpp
SECAM = 75% color bars
Horizontal Timebase started (subaddress 00)
Vertical Breathing control set to 00; V9 = 0 V
All other analog controls set to midrange 32
Video Peaking "P1, P2, P3" bits high

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**TEST CONDITIONS** (unless otherwise noted.)

| |
|---|
| $V_{CC}$ = 5.0 V<br>$I_{ref}$ = 70 µA<br>$T_A$ = 25°C |
| Video Composite Input = 1.0 Vpp<br>– Black–to–White = 0.7 Vpp<br>– Black–to–Sync = 0.3 Vpp |
| Horizontal Timebase Started (Reg. 00) |
| Vertical Breathing Control Set to 00 |
| Pin 9 = 0 V<br>Pin 10 = 5.0 V |
| PAL/NTSC = 75% Color Bars<br>–Burst = 300 mVpp<br>SECAM = 75% Color Bars (MC44002 only) |
| All Analog Controls Set to Midpoint (32) |
| Luma Peaking at Min. (P1 – P3 = 111) |

**Control Bits Setup**

| Name | Value | Function Status |
|---|---|---|
| V1/V2 | 1 | Video Input 1 Selected |
| H EN | 0 | Horizontal Drive Enabled |
| BRI EN | 1 | "Bright" Sample "On" |
| $\overline{\text{HGAIN1}}$ | 0 | Horizontal Phase Detector Gain Reduced by 3 Enabled |
| YX EN | 0 | Luma Matrix Disabled |
| Y1 EN | 1 | Luma from Filters "On" |
| D EN | 0 | RGB Inputs Enabled |
| XS | 0 | Pin 33 Crystal Enabled |
| TEST | 1 | Outputs Sampled Once/Field |
| FSI | 0 | 50 Hz Field Rate |
| T3 | 1 | Low Pass Filter Enabled |
| VD1 | 1 | 4:3 Display Mode |
| 2xFh | 0 | Horizontal Drive at 1xFh |
| NORM | 0 | Horizontal Reference Divider for 17.7 MHz |
| HGAIN2 | 1 | Horizontal Phase Detector Gain Reduced by 2 Enabled |
| INTSEL | 1 | Long Vertical Time Constant |
| Y2 EN | 0 | External Luma Input "Off" |
| SSD | 0 | SECAM Mode Select Enabled |
| CALKIL | 1 | Horizontal Calibration Loop Enabled |
| BAI | 1 | Vertical Blanking for 625 Lines |
| S–VHS | 1 | Composite Video Input |

## ELECTRICAL CHARACTERISTICS

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **BUS REQUIREMENTS** | | | | | | |
| Maximum Output Low Voltage<br>$I_{sink}$ = 1.0 mA, Device in "Read" Mode | $V_{OL(max)}$ | 5 | – | 0.7 | – | V |
| Maximum Sink Current<br>$V_{OL}$ = 0.7 V, Device in "Read" Mode | $I_{sink(max)}$ | 5 | – | 1.0 | – | mA |
| Minimum Input High Voltage | $V_{IH(min)}$ | 5 | – | 3.0 | – | V |
| Maximum Input Low Voltage | $V_{IL(max)}$ | 5 | – | 1.5 | – | V |
| Maximum Rise Time<br>Between $V_{IH}$ and $V_{IL}$ Levels | $t_{r(max)}$ | 4, 5 | – | 1.0 | – | µs |
| SCL Clock Frequency | $f_{SCL}$ | 4 | – | – | 100 | kHz |
| **HORIZONTAL TIMEBASE** | | | | | | |
| Free–Running Frequency (Calibration Mode)<br>17.734475 MHz Crystal. "NORM" Bit = 0;<br>"H EN" Bit = 1 (Horizontal Drive Disabled)<br>14.31818 MHz Crystal. "NORM" Bit = 1;<br>"H EN" Bit = 1 (Horizontal Drive Disabled) | – | 31 | <br>15.39<br><br>15.42 | <br>15.625<br><br>15.75 | <br>15.85<br><br>15.98 | kHz |
| H–Loop 1 (Pin 15 Current Forced to ± 20 µA)<br>Minimum Frequency<br>Maximum Frequency<br>Frequency Range | – | 12 | <br>13.85<br>16.05<br>– | <br>14.25<br>16.55<br>2.3 | <br>14.65<br>17.05<br>– | kHz |
| VCO Control Gain | – | 12, 15 | 1.9 | 2.4 | 2.9 | kHz/V |
| Phase Detector Gain<br>"$\overline{\text{HGAIN1}}$" Bit = 1; "HGAIN2" Bit = 0 | – | 15 | 18 | 27 | 39 | µA/µs |
| Phase Detector Gain Reduction Factor<br>"$\overline{\text{HGAIN1}}$" Bit Switched from 1 to 0<br>"HGAIN2" Bit Switched from 0 to 1 | – | 15 | <br>2.5<br>1.75 | <br>3.0<br>2.0 | <br>3.5<br>2.25 | – |
| Line Drive Output Saturation Voltage<br>I12 = 1.0 mA | – | 12 | – | 0.25 | 0.5 | V |
| Horizontal Drive Pulse Low<br>Defined by Internal Counter, Deflection Transistor "Off", Period is 64 µs | – | 12 | – | 27 | – | µs |
| Horizontal Flyback Input Resistance<br>V13 = 2.0 V | – | 13 | – | 50 | – | kΩ |
| Horizontal Flyback Clamping Voltages<br>I13 = 500 µA<br>I13 = –50 µA | – | 13 | <br>–<br>– | <br>5.7<br>–0.5 | <br>–<br>– | V |
| Horizontal Flyback Threshold Current<br>Should be Externally Limited to 500 µA Peak by an External Resistor | – | 13 | 30 | – | – | µA |
| Horizontal Phase Control Range<br>Flyback Duration: 12 µs | – | 12 | 8.0 | – | 12 | µs |
| External Delay Compensation<br>From Horizontal Drive to Center of Flyback Pulse.<br>Flyback Duration: 12 µs | – | 12, 13 | 6.0 | – | 18 | µs |
| **VERTICAL TIMEBASE** (All Values are Related to Pin 3 Reference Current) | | | | | | |
| Vertical Drive Amplitude (4:3 Display)<br>(00)<br>(32)<br>(63)<br>C6 = 82 nF, Assuming Zero Tolerance Capacitance, "VDI" Set to "1" | – | 7 | <br>1.15<br>1.55<br>1.95 | <br>1.33<br>1.75<br>2.18 | <br>1.5<br>1.95<br>2.4 | V |
| Vertical Drive Amplitude Control Range (4:3 Display)<br>C6 = 82 nF, Assuming Zero Tolerance Capacitance, "VDI" Set to "1", Vertical Amplitude Varied from (00) to (63) | – | 7 | 0.75 | 0.85 | 1.0 | V |

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**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **VERTICAL TIMEBASE** (All Values are Related to Pin 3 Reference Current) | | | | | | |
| Ramp Amplitude Ratio Between 4:3 and 16:9 Display Modes<br>Vertical Amplitude = (32) | – | 7 | 0.7 | 0.8 | 0.9 | – |
| Maximum Ramp Amplitude Change With 525/625 Mode Change | – | 7 | – | 2.0 | – | % |
| Vertical Ramp Low Voltage (4:3 Display)<br>Pin 6 Voltage Set to 0 V, "VDI" Set to "1", Vertical Position = (00) | – | 7 | – | 0.65 | – | V |
| Vertical Ramp Low Voltage (16:9 Display)<br>Pin 6 Voltage Set to 0 V, "VDI" Set to "0", Vertical Position = (00), Measured After 16:9 Holding Period | – | 7 | – | 0.85 | – | V |
| Vertical Ramp High Voltage<br>Pin 6 Open, "VDI" Set to "0" or "1", Vertical Position = (63) | – | 7 | – | 4.15 | – | V |
| Vertical Ramp Position Control Range<br>Versus Vertical Ramp Voltage at Vertical Position (32), Measured at $V_m$, "VDI" Set to "0" or "1", Vertical Position Varied from (00) to (63) | – | 7 | ±0.5 | ±0.75 | ±1.0 | V |
| Vertical Ramp Clamping Duration ($t_c$)<br>Defined by Internal Counter | – | 7 | – | 512 | – | µs |
| Maximum Output Source Current | – | 7 | 1.0 | – | – | mA |
| Maximum Output Sink Current | – | 7 | 200 | – | – | µA |
| Vertical Linearity<br>(00)<br>(63) | – | 7 | <br>–<br>– | <br>0.8<br>1.1 | <br>–<br>– | – |
| Change in Ramp current as Pin 9 Current Varied from 0 to 6.4 µA<br>Vertical Breathing Correction = (63)<br>Vertical Breathing Correction = (00) | – | 6 | <br>0.15<br>– | <br>0.75<br>0 | <br>1.3<br>– | µA |
| Gain V7/V6 | – | 6, 7 | 0.9 | 0.95 | 1.0 | V/V |
| **E–W CORRECTION** (V6(b) = 0.2 V, V6(m) = 1.1 V, V6(e) = 2.0 V) | | | | | | |
| Horizontal Amplitude<br>(00)<br>(63)<br>Corner Correction = (00), Tilt = (32), Parabola Amplitude = (00), Measured at $T_m$. | – | 8 | <br>0<br>150 | <br>0.2<br>300 | <br>20<br>– | µA |
| Parabola Amplitude<br>(00)<br>(63)<br>Corner Correction = (00), Horizontal Amplitude = (32), Tilt = (32), Measured at $T_b$, $T_m$ and $T_e$. | – | 8 | <br>0<br>100 | <br>0.2<br>250 | <br>10<br>– | µA |
| Corner Correction<br>(00)<br>(63)<br>Horizontal Amplitude = (63), Parabola Amplitude = (00), Tilt = (32), Measured at $T_b$, $T_m$ and $T_e$. | – | 8 | <br>0<br>– | <br>0.2<br>–150 | <br>10<br>–30 | µA |
| Parabola Tilt<br>(00)<br>(63)<br>Corner Correction = (00), Horizontal Amplitude = (32), Parabola Amplitude = (32), Measured at $T_b$, $T_m$ and $T_e$. | – | 8 | <br>–<br>– | <br>1.9<br>–1.9 | <br>–<br>– | – |
| E–W Drive Output Voltage | – | 8 | 1.0 | – | $V_{CC}$ | V |

**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **E–W CORRECTION** (V6(b) = 0.2 V, V6(m) = 1.1 V, V6(e) = 2.0 V) | | | | | | |
| E–W DACs Differential Non–Linearity Error | – | 8 | | | | LSB |
| At Minor Transitions: Steps 0–1: 1–2; 3–4; 7–8; 15–16. | | | –1.0 | – | 1.0 | |
| At Major Transition: Step 31–32 | | | –2.0 | – | 1.0 | |
| **SYNC SEPARATOR** | | | | | | |
| Sync Amplitude to Operate the Device | – | 2, 40 | 100 | – | – | mV |
| From Black to Sync, Black Picture, Standard Timing Specifications on Sync Signal | | 22, 23, 24, 25 | – | 160 | – | |
| Vertical Sync Separator Delay Time: $t_d$ | – | 2, 40 | | | | µs |
| "INTSEL" = 0 | | | – | 36 | – | |
| "INTSEL" = 1 | | | – | 68 | – | |
| From Vertical Sync Pulse to Vertical Ramp Reset | | | | | | |
| Vertical Sync Window | – | 2, 40, 22, 23, 24, 25 | 448 | – | 740 | Half Lines |
| **COMPOSITE VIDEO PROCESSING** (All measurements in NORMAL mode, unless otherwise noted.) | | | | | | |
| Composite Video Input Amplitude | – | 2, 40 | 0.7 | 1.0 | 1.4 | Vpp |
| Load Impedance 75 Ω, Less than 5% Distortion | | | | | | |
| Video 1/Video 2 Input Crosstalk | – | 29 | – | – | –40 | dB |
| @ f = (2.0 MHz), Measured on Y1 Output | | | | | | |
| Variable Input LPF Cut–Off Frequency | – | 29 | | | | MHz |
| 17.7 MHz Crystal Selected | | | – | 6.0 | – | |
| 14.3 MHz Crystal Selected | | | – | 4.85 | – | |
| Chroma Subcarrier Rejection | – | 29 | | | | dB |
| PAL 4.43 MHz (17.7 MHz Crystal Selected) | | | 25 | 30 | – | |
| NTSC 3.58 MHz (14.3 MHz Crystal Selected) | | | 25 | 30 | – | |
| SECAM ($F_oR$ and $F_oB$) (17.7 MHz Crystal Selected) | | | 18 | 20 | – | |
| Y1 Output Resistance | – | 29 | – | – | 300 | Ω |
| Y1 Bandwidth (–3.0 dB) | – | 29 | | | | MHz |
| PAL | | | 2.5 | 3.0 | – | |
| Minimum Peaking, "T3" Set to 1 (Input LPF "On") | | | | | | |
| SECAM | | | 2.5 | 3.0 | – | |
| Minimum Peaking, "T3" Set to 0 (Input LPF "Off") | | | | | | |
| Luma Peaking Range | – | 29 | 6.0 | 8.5 | – | dB |
| Measured at 3.0 MHz, 17.7 MHz Crystal Selected | | | | | | |
| Luma Gain (@ 100 kHz) | – | 2, 40, 29 | 0.9 | 1.1 | 1.3 | V/V |
| Overshoot | – | 29 | – | 5.0 | – | % |
| Peaking at Step 3 (100) | | | | | | |
| Source Impedance | – | 2, 40 | 0 | – | 1.5 | kΩ |
| Luma Delay Range | – | 29 | | | | ns |
| PAL/SECAM (17.7 MHz Crystal Selected) | | | – | 280 | – | |
| NTSC 3.58 (14.3 MHz Crystal Selected) | | | – | 350 | – | |
| Video In to Luma Out Delay Difference Between PAL and SECAM (MC44002 only) | – | 29, 40 | – | 260 | – | ns |
| Luma Delay Minimum: (D1 D2 D3) = (0 0 0), Green to Magenta Transition, "T3" Set to 1 in PAL, to 0 in SECAM | | | | | | |
| **PAL/NTSC DECODER** | | | | | | |
| Chroma Output Variation | – | 36, 37 | – | – | 3.0 | dB |
| For a Burst Input Varied from 60 mV to 600 mV | | | | | | |
| Color Kill Attenuation | – | 36, 37 | 40 | – | – | dB |
| Referred to Standard Color Video Input, Monochrome Mode Selected | | | | | | |

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**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **PAL/NTSC DECODER** | | | | | | |
| Color Difference Output Distortion<br>@ 1.5 V Output Signal | – | 36, 37 | – | – | 5.0 | % |
| Residual Chroma Subcarrier Rejection<br>PAL<br>NTSC<br>Referred to Video Input | – | 36, 37 | <br>40<br>40 | <br>–<br>– | <br>–<br>– | dB |
| Oscillator Pull–In Range<br>PAL<br>NTSC<br>Referred to Nominal Subcarrier Frequency, with Ideal Xtal | – | 32, 33 | <br>±350<br>±400 | <br>–<br>– | <br>–<br>– | Hz |
| R–Y, B–Y Channel Separation | – | 36, 37 | 30 | – | – | dB |
| B–Y/R–Y Amplitude Ratio<br>At Standard Color Bars Signal | – | 36, 37 | – | 1.3 | – | V/V |
| B–Y/R–Y Amplitude Ratio Spread<br>At Standard Color Bars Signal | – | 36, 37 | –2.0 | – | 2.0 | dB |
| Minimum Burst Level for "ACC Active" Flag "On"<br>Standard Set to PAL or NTSC, Increasing Burst Level Steps | – | 2, 40 | – | 10 | 20 | mVpp |
| Minimum Burst Level for "PAL Identified" Flag "On"<br>Standard Set to PAL or NTSC, Increasing Burst Level Steps | – | 2, 40 | – | 5.0 | 20 | mVpp |
| Maximum Burst Level for "ACC Active" Flag "Off"<br>Standard Set to PAL or NTSC, Decreasing Burst Level Steps | – | 2, 40 | – | 5.0 | – | mVpp |
| Maximum Burst Level for "PAL Identified" Flag "Off"<br>Standard Set to PAL or NTSC, Decreasing Burst Level Steps | – | 2, 40 | – | 1.0 | – | mVpp |
| (B–Y) Color Difference Output Levels<br>Relative to 75% Color Bars | – | 36 | 0.7 | 1.1 | 1.5 | V |
| Hue DAC Control Range<br>Hue Control Register Varying from (00) to (63) | – | 36, 37 | ±20 | – | – | Deg |
| Chroma to Luma Delay<br>PAL<br>NTSC<br>Measured on (B–Y) Output, Luma Delay Set to Minimum: (D1 D2 D3) = (0 0 0), Green to Magenta Transition, "T3" Set to 1 | – | 29, 36 | <br>–<br>– | <br>80<br>100 | <br>–<br>– | ns |
| **DELAY LINE CONTROL SIGNALS** | | | | | | |
| System Select<br>PAL<br>NTSC<br>SECAM (MC44002 only)<br>EXTERNAL | – | 30 | <br>–<br>1.4<br>2.75<br>3.7 | <br>75<br>1.65<br>3.0<br>4.0 | <br>400<br>1.9<br>3.25<br>4.3 | <br>mV<br>V<br>V<br>V |
| Sandcastle<br>Level 1<br>Level 2<br>Level 3<br>Level 4<br>See Figure 4 | – | 31 | <br>3.7<br>2.75<br>1..3<br>– | <br>4.0<br>2.95<br>1.55<br>75 | <br>4.3<br>3.15<br>1.8<br>– | <br>V<br>V<br>V<br>mV |
| Sandcastle<br>t1<br>t2<br>See Figure 4, Values Defined by Internal Counter | – | 31 | <br>5.0<br>4.0 | <br>6.0<br>5.0 | <br>7.0<br>6.0 | µs |

**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **S–VHS VIDEO PROCESSING** (S–VHS Set to 0, "T3" Set to 0) | | | | | | |
| Y1 Bandwidth<br>Luma Peaking Set to Minimum | – | 29 | 3.2 | 3.5 | – | MHz |
| Minimum Burst Level for "ACC Active" Flag "On"<br>Standard Set to PAL or NTSC, Increasing Burst Level Steps | – | 2, 40 | – | 10 | 20 | mVpp |
| Minimum Burst Level for "PAL Identified" Flag "On"<br>Standard Set to PAL or NTSC, Increasing Burst Level Steps | – | 2, 40 | – | 5.0 | 20 | mVpp |
| Maximum Burst Level for "ACC Active" Flag "Off"<br>Standard Set to PAL or NTSC, Decreasing Burst Level Steps | – | 2, 40 | – | 5.0 | – | mVpp |
| Maximum Burst Level for "PAL Identified" Flag "Off"<br>Standard Set to PAL or NTSC, Decreasing Burst Level Steps | – | 2, 40 | – | 1.0 | – | mVpp |
| Video In to Luma Out Delay Difference Between S–VHS and Normal Mode<br>Luma Delay Minimum in Normal Mode, Set to Step 6 in S–VHS Mode, Green to Magenta Transition, "T3" Set to 1 in Normal Mode, to 0 in S–VHS Mode | – | 2, 40, 29 | – | 310 | – | ns |
| Chroma to Luma Delay Difference Between S–VHS and Normal Mode<br>Measured on (B–Y) Output, Luma Delay Minimum in Normal Mode, Set to Step 6 in S–VHS Mode, Green to Magenta Transition, "T3" Set to 1 in Normal Mode, to 0 in S–VHS Mode | – | 29, 36, 2, 40 | – | 60 | – | ns |
| **SECAM DECODER (MC44002 ONLY)** | | | | | | |
| Minimum Subcarrier Level for "SECAM Identified" Flag<br>Measured at $f_oR$ | – | 2, 40 | – | 10 | 20 | mVpp |
| Color Kill Attenuation<br>Monochrome Mode Selected Referred to Color Difference Output Signal with SECAM Selected and Identified | – | 36, 37 | 40 | 50 | – | dB |
| Color Difference Zero Level Error<br>Relative to 75% Color Bars, Difference Between Signal Measured at t1 and Active Black Level (Black Bar) | – | 36, 37 | – | ±1.0 | ±3.0 | % |
| Color Difference Output Distortion<br>Subcarrier Level at $f_oR$ = 20–400 mV @ 1.5 V Output Signal | – | 36, 37 | – | – | 5.0 | % |
| Transient Response<br>(B–Y)<br>(R–Y)<br>Generator Rise Time – 600 ns (B–Y), Green to Magenta Transition, Measured Between 10% and 90% Levels | – | <br>36<br>37 | <br>–<br>– | <br>650<br>750 | <br>800<br>900 | ns |
| B–Y/R–Y Amplitude<br>Ratio<br>Ratio Spread<br>Relative to 75% Color Bars | – | 36, 37 | <br>–<br>–2.0 | <br>1.3<br>– | <br>–<br>2.0 | <br>V/V<br>dB |
| Residual Carrier and Harmonics (4.0 to 13.5 MHz)<br>At Standard Color Bars Signal | – | 36, 37 | – | – | 1.0 | % |
| (B–Y) Color Difference Output Levels<br>Relative to 75% Color Bars | – | 36 | – | 1.1 | – | V |
| PAL/SECAM Color Difference Ratio<br>Nominal Input Signals | – | 36 | 0.8 | 1.0 | 1.2 | – |

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**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **SECAM DECODER (MC44002 ONLY)** | | | | | | |
| Chroma to Luma Delay<br>Luma Delay Set to Minimum: (D1 D2 D3) = (0 0 0), Green to Magenta Transition, "T3" Set to 0 | – | 29, 36 | – | 420 | – | ns |
| Patterning<br>Full Screen 75% Color Frequency, 500 kHz Low Pass Filter, Relative to Black to Color Output Signal | – | 36 | – | – | 5.0 | % |
| Line to Line Luma Levels Difference<br>Full Screen 75% Yellow Color Frequency, Relative to Black to Yellow Output Signal | – | 29 | – | – | 1.5 | % |
| Chroma to Luma Delay Difference Between PAL and SECAM<br>Measured on (B–Y) Output, Luma Delay Set to Minimum: (D1 D2 D3) = (0 0 0), Green to Magenta Transition, "T3" Set to 0 in SECAM, to 1 in PAL | – | 29, 36 | – | 340 | – | ns |
| **COLOR DIFFERENCE STAGES** | | | | | | |
| RGB Input Amplitude<br>Black to Peak (Less than 5% Distortion at RGB Outputs) | – | 22, 23, 24 | 500 | 700 | 1000 | mVpp |
| Fast Commutate<br>Low Level<br>High Level | – | 21 | <br>–<br>1.0 | <br>–<br>– | <br>0.5<br>– | V |
| Y2 Input Amplitude<br>(Less than 5% Distortion at RGB Outputs) | – | 25 | 0.7 | 1.0 | 1.4 | Vpp |
| Color Difference Input Amplitude<br>(Less than 5% Distortion at RGB Outputs) | – | 26, 27 | – | – | 1.8 | Vpp |
| Y2/Y1 Crosstalk<br>Measured at RGB Outputs, Measured at f = (2.0 MHz) | – | 25, 29 | – | –40 | –30 | dB |
| RGB to Y Crosstalk<br>Measured at RGB Outputs, Measured at f = (2.0 MHz) | – | 22, 23, 24, 25, 29 | – | –40 | –30 | dB |
| RGB Transconductance Bandwidth (@ –1.0 dB) | – | 24, 17, 23, 18, 22, 19 | 6.5 | – | – | MHz |
| Gain Reduction in ACL Mode<br>Pin 10 Voltage Varying from 0 to 5.0 v | – | 10, 17, 18, 19 | – | 12.5 | – | dB |
| Gain Reduction Sensitivity in ACL Mode<br>Pin 10 Voltage Varying from 2.0 to 2.5 V | – | 10, 17, 18, 19 | – | 20 | – | dB/V |
| Demodulation Angles and Amplitudes | – | – | | | | Deg |
| Mode A Rm | | | – | 0.562 | – | |
| Ra | | | – | 90 | – | |
| Gm | | | – | 0.344 | – | |
| Ga | | | – | 237 | – | |
| Mode B Rm | | | – | 0.9 | – | |
| Ra | | | – | 100 | – | |
| Gm | | | – | 0.3 | – | |
| Ga | | | – | 236 | – | |
| Mode C Rm | | | – | 0.9 | – | |
| Ra | | | – | 106 | – | |
| Gm | | | – | 0.3 | – | |
| Ga | | | – | 240 | – | |
| Mode D Rm | | | – | 0.91 | – | |
| Ra | | | – | 106 | – | |
| Gm | | | – | 0.31 | – | |
| Ga | | | – | 246 | – | |
| Definitions: Rm/Gm = Module, Ra/Ga = Argument | | | | | | |

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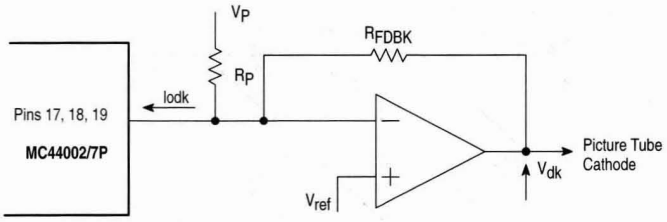
**ELECTRICAL CHARACTERISTICS (continued)**

| Parameter | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **RGB OUTPUT STAGES** | | | | | | |
| Low Dark Sample Output Current<br>Red<br>Green<br>Blue<br>Dark Sample Cathode Current 5.0 to 15 µA, DC<br>DAC Set to Full Scale, See Figure 1 | – | 17, 18, 19 | <br>–<br>–<br>– | <br>–<br>–<br>– | <br>3.15<br>3.15<br>3.15 | mA |
| High Dark Sample Output Current<br>Red<br>Green<br>Blue<br>Dark Sample Cathode Current 5.0 to 15 µA, DC<br>DAC Set to Zero, See Figure 1 | – | 17, 18, 19 | <br>3.95<br>3.95<br>3.95 | <br>–<br>–<br>– | <br>–<br>–<br>– | mA |
| Blanking Output Current | – | 17, 18, 19 | 6.0 | – | – | mA |
| Maximum Y to RGB Output Transconductance<br>Gain DAC Set to Full Scale | – | 17, 18, 19 | 6.0 | 7.0 | 8.0 | mA/V |
| Brightness<br>(00)<br>(63)<br>Wrt Dark Sample Cathode Voltage,<br>High Voltage Output Stage Transimpedance<br>39 kΩ, Dark Sample Cathode Current 15 µA, Dark<br>Sample Cathode Voltage 140 V | – | – | <br>–<br>– | <br>30<br>–20 | <br>–<br>– | V |
| RGB Dark Sample Current Intensity Range<br>RGB Intensity DACs Varying from (00) to (63) | – | 20 | 15 | 20 | – | dB |
| Bright to Dark Sample Current Ratio | – | 20 | 8.0 | 9.5 | 11 | µA/µA |
| Leakage Loop<br>Sink Current<br>Source Current | – | 20 | <br>20<br>5.0 | <br>–<br>– | <br>–<br>– | µA |
| Average Beam Current Detection Level<br>Excess Flag<br>Overload Flag | – | 9 | <br>0.9<br>–1.3 | <br>1.0<br>–1.2 | <br>1.1<br>–1.1 | V |
| Peak Beam Current Detection Level | – | 20 | 6.5 | 6.8 | 7.1 | V |

**Figure 1. Example of Output Circuitry**




$V_p$, $V_{ref}$, $R_{FDBK}$ and $R_p$ values will determine the exact operating point.

For example, let us take:
$V_p$ = 5.0 V  $R_{FDBK}$ = 39 kΩ
$V_{ref}$ = 3.6 V
$R_p$ = 6.8 kΩ

The formula giving the Dark Cathode Voltage with above circuit is: $V_{dk} = V_{ref} + R_{FDBK}*(V_{ref} - V_p + Iodk*R_p) / R_p$

With above application, component values and Iodk specifications, all 3 cathodes on all devices will always have a range of at least 120 V to 150 V.

By changing the values of $V_p$, $V_{ref}$ and $R_p$, the cathode voltage range may be shifted up or down as required.

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**Figure 2. Vertical Waveforms**

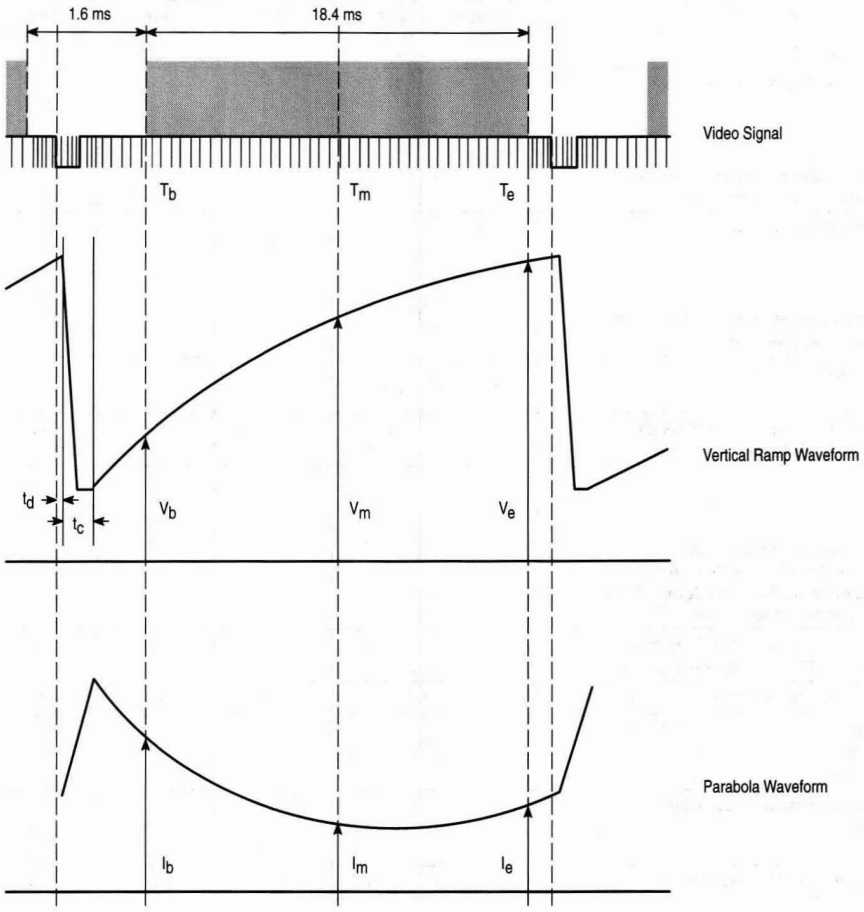
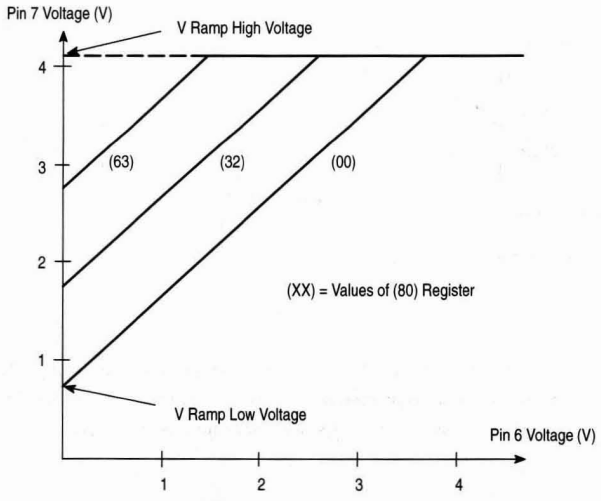



**Figure 3. Vertical Ramp Positions (V7 versus V6)**



**Definitions**

$$\text{Parabola Amplitude} = \frac{(i_b + i_e)}{2} - i_m$$

$$\text{Parabola Tilt} = \frac{(i_e - i_b)}{\text{Parabola Amplitude}}$$

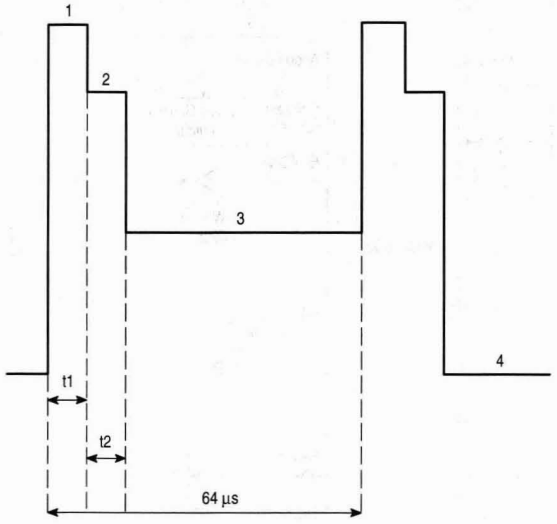
$$\text{Horizontal Amplitude} = i_m$$

$$\text{Vertical Amplitude} = V_e - V_b$$

$$\text{Vertical Linearity} = \frac{(V_e - V_m)}{V_m - V_b}$$

Corner correction is calculated in the same way as Parabola Amplitude.

**Figure 4. Sandcastle Output (Pin 31)**

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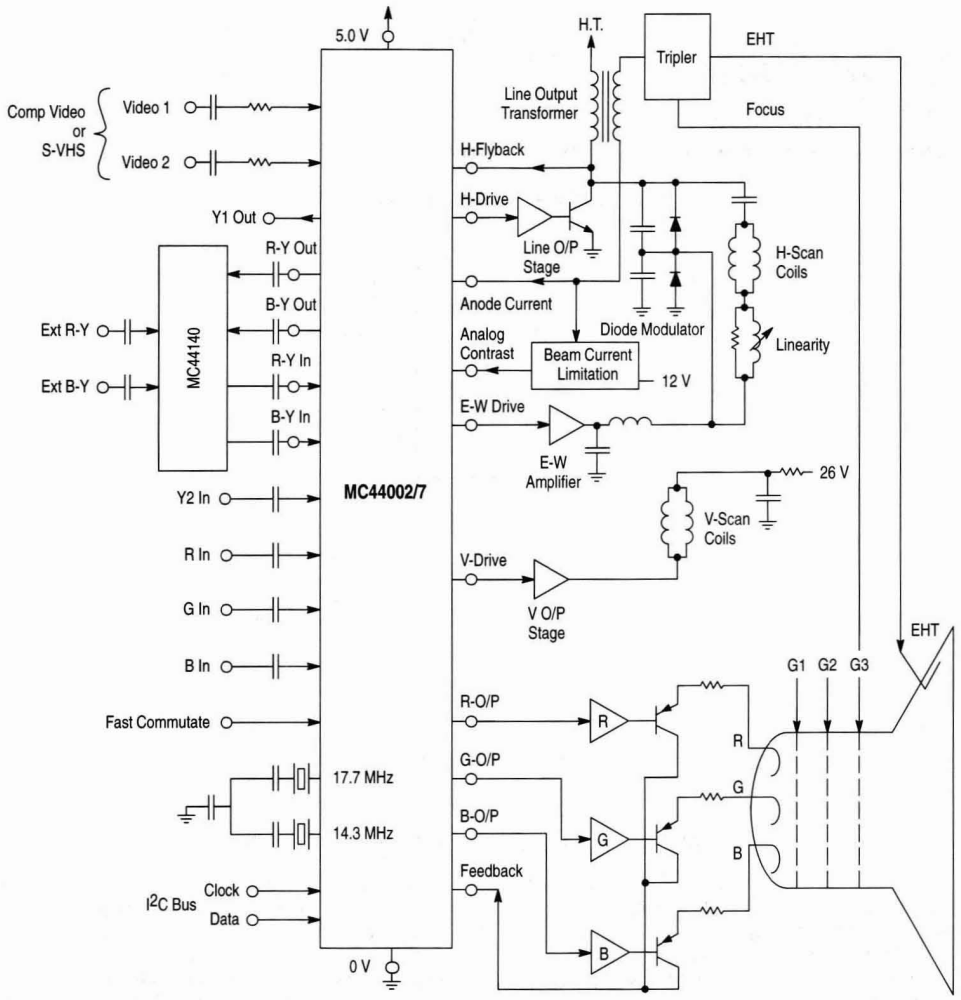
## GENERAL DESCRIPTION OF THE CHROMA 4 SYSTEM

Figure 5 shows a simplified block diagram representation of the basic system using the MC44002/7 and its companion device the MC44140 chroma delay line. The MC44002/7 has been designed to carry out all the processing of video signals, display controls and timebase functions. There are two video inputs which can be used for normal composite video or separate Y and C inputs. In either case, the inputs are interchangeable and selection is made via the $I^2C$ bus. The video is decoded within the MC44002/7 and involves separation, filtering, delay of the luminance part of the signal and demodulation of the chroma into color difference signals. The luminance (called Y1) together with the demodulated R-Y and B-Y are all then brought out from the IC. The color difference signals then enter the MC44140 which performs color correction in PAL and the delay line function in SECAM. Corrected color difference signals then re-enter the MC44002/7.

**Figure 5. Connection to TV Chassis**




The next stage is called the color difference stage where a number of control functions are carried out together with matrixing of the components to derive RGB signals. At this point a number of auxiliary signals may also be switched in, again all under MCU control. External RGB (text) and Fast Commutate enter here; also an external luminance (Y2) may be used instead of Y1. External R-Y and B-Y are switched in via the delay line circuit to save pins on the main device. The Y2 and External R-Y, B-Y will obviously be of considerable benefit from the system point of view for use with external decoders.

The final stage of video processing is the RGB outputs which drive the high voltage amplifiers connected to the tube cathodes. These outputs are controlled by a sophisticated digital servo-loop which is maintained and stabilized by a sequentially sampled beam current feedback system. Automatic gray scale control is featured as a part of this system.

Both horizontal and vertical timebases are incorporated into the MC44002/7 and control is via the I2C bus. The horizontal timebase employs a dual loop system of a PLL and variable phase shifter, and the vertical uses a countdown system. For the vertical, a field rate sawtooth is available which is used to drive an external power amplifier with flyback generator (usually a single IC). The line output consists of a pulse which drives a conventional line output stage in the normal way. The line flyback pulse is sensed and used by the second loop for horizontal phase shift.

Where E-W correction is required, a parabola waveform is available for this which, with the addition of a power amplifier, can be used with a diode modulator type line output stage for dynamic width and E-W control. The bottom of the EHT overwinding is returned to the MC44002/7 and is used for anode current monitoring.

Fast beam current limitation is also made possible by the use of an analog contrast control.

A much more detailed description of each stage of the MC44002/7 will be found in the next section. Information on the delay line is to be found in its own data sheet.

## Introduction

The following information describes the basic operation of the MC44002/7 IC together with the MC44140 chroma delay line. The MC44002/7 is a highly advanced circuit which performs all the video processing, timebase and display functions needed for a modern color TV. The device employs analog circuitry but with the difference that all its advanced features are under processor control, enabling external filtering and potentiometer adjustments to be removed completely. Sophisticated feedback control techniques have been used throughout the design to ensure stable operating conditions and the absence of drift with age.

The IC described herein is one of a new generation of TV circuits, which make use of a serial data bus to carry out control functions. Its revolutionary design concept permits a level of integration and degree of flexibility never achieved before. The MC44002/7 consists of a single bipolar VLSI chip which uses a high density, high frequency, low voltage process called MOSAIC 1.5. Contained within this single 40 pin package is all the circuitry needed for the video signal processing, horizontal and vertical timebases and CRT display control for today's color TV. Furthermore, all the user controls and manufacturer's set-up adjustments are under the control of the processor I2C bus, eliminating the need for potentiometer controls. The MC44002/7 offers an enormous variety of different options configurable in software, to cater to virtually any video standard or circumstance commonly met. The decoder section offers full multistandard capability, able to handle PAL, SECAM (MC44002 only) and NTSC standards with 4 matrix modes available. Practically all the filtering is carried out onboard the IC by means of sampled data filters, and requires no external components or adjustment.

## Digital Interface

One of the most important features of MC44002/7 is the use of processor control to replace external potentiometer and filter adjustments. Great flexibility is possible using processor control, as each user can configure the software to suit their individual application. The circuit operates on a bidirectional serial data bus, based on the well known I2C bus. This system is rapidly becoming a world standard for the control of consumer equipment.

## I2C Bus

It is not within the scope of this data sheet to describe in detail the functioning of the I2C bus. Basically, the I2C bus is a two-wire bidirectional system consisting of a clock and a serial data stream. The write cycle consists of 3 bytes of data and 3 acknowledge bits. The first byte is the Chip Address, the second the Sub-address to identify the location in the memory, and the third byte is the data. When the address' Read/Write bit is high, the second and third bytes are used to transmit status flags back to the MCU.

Figure 6 shows a block diagram of the MC44002/7 Bus Interface/Decoder. To begin with, the start bit is recognized by means of the data going low during CLK high. This causes the Counter and all the latches to be reset. For a write operation, the Write address ($88) is read into the Shift Register. If the correct address is identified, the Chip Address Latch is set and at CLK 9 an acknowledge is sent.

The second byte is now read into the Shift Register and is used to select the Sub-address. At CLK 18 a Sub-address Enable is sent to the memory to allow the Data in the register to be changed. Also, at CLK 18 another acknowledge is sent.

The third byte is now read into the Shift Register and the Data bussed into the memory. The Data in the Sub-address location already selected is then altered. A third acknowledge is sent at CLK 27 to complete the cycle.

A Read address ($89) indicates that the MCU wants to read the MC44002/7 status flags. In this instance, the Read/Write Latch is set, causing the Memory Enable and Subaddress Enable to be inhibited, and the flags to be written onto the data line. Two of the status flags are permanently wired one-high and one-low (O.K. and Fault), to provide a check on the communication medium between the MC44002/7 and the MCU.

At start-up the Counter is automatically reset and the Data for each Sub-address is read in from the MCU. Only after the entire memory contents have been transmitted, is Data 00 sent to register 00 to start the Horizontal Drive.

The MC44002/7 needs the full 27 clock cycles, or a stop condition, to properly release the I2C bus.

**Figure 6. I2C Bus Interface and Decoder**

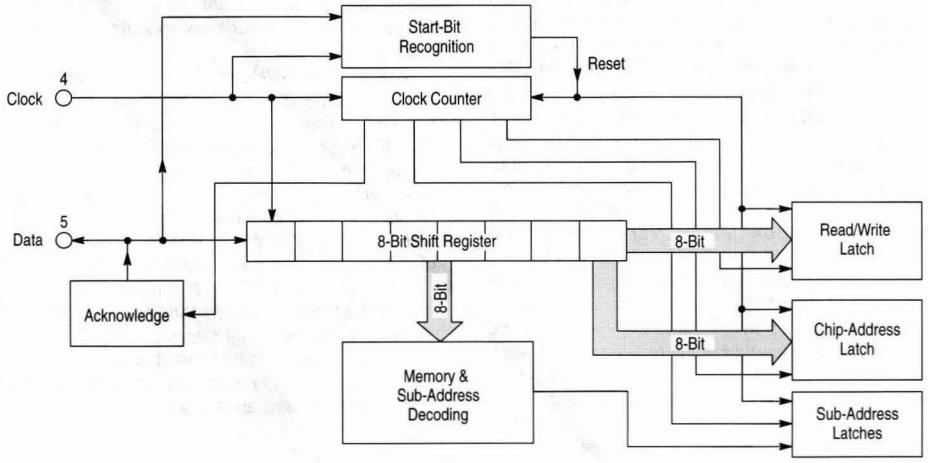



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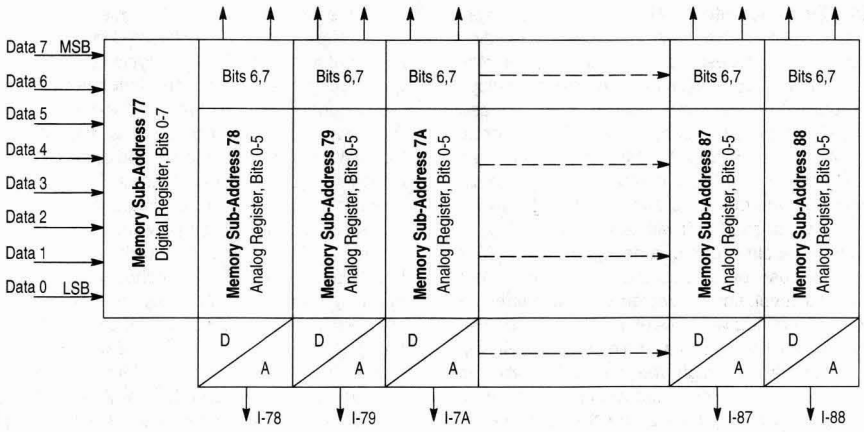
**Figure 7. MC44002/7 Memory Map**




**Memory**

Figure 7 shows a diagram of the MC44002/7 Memory Map. It has 18 bytes of memory which are located at hex sub-addresses 77 to 88. Sub-address 77 is used to set up the vertical timebase mode of the IC and for S-VHS switching, and consists of 8 separate data bits. The remaining 17 bytes use the least significant 6-bits as an analog control register. The contents of each are D/A converted, providing an analog control current which is distributed to the appropriate part of the circuit. Bits 6 and 7 are used singularly for switching control functions.

**Chroma Decoder**

The main function of this section is to decode the incoming composite video, which may be in any of the PAL, NTSC or SECAM (MC44002 only) Standards, and to retrieve the luminance and color difference signals. In addition, the signal filtering and luma delay line functions are carried out in this section by means of sampled data filters.

The entire decoder section operates in sampled data mode using clocks generated by external crystals. The oscillator, which is phase-locked in the usual way for PAL/NTSC modes, provides the clock function for the whole circuit. The crystals are selected by the MCU by means of a control bit (XS). Only crystals appropriate to the standards which are going to be received need to be fitted. A 17.7 MHz crystal (4x PAL subcarrier) is used for PAL and SECAM systems (50 Hz, 625 lines); and 14.3 MHz (4x NTSC subcarrier) for the NTSC system (60 Hz, 525 lines). Nearly all the filters, together with the luma delay line and peaking, have been integrated, requiring no external components or any adjustment. The filter characteristics are entirely determined by the clocks and by capacitor ratios, and are thus completely independent of variations in the manufacturing process. The PAL/NTSC subcarrier PLL and ACC loop filters have not been integrated in order to facilitate testing. These filters consist of fixed external components.

Figure 8 is a block diagram of the main features of the chroma decoder. Selection is first made between the Video 1 and Video 2 inputs. These may be either normal composite video or separate luma and chroma which may enter the IC at either pin. Commands from the MCU are used to route the signals through the appropriate delay and filter sections.

In PAL/NTSC, a variable low pass filter, which can be software bypassed (control bit T3), is then used to compensate for IF filtering and the Q of the external sound traps. Filter response is controlled by means of control bits T1 and T2. It is not recommended to use this filter in SECAM or in S–VHS, as luma–chroma delays will not be optimized. Next, the video enters the luma path. The PAL/NTSC or SECAM chroma signals are separated out by transversal high pass filters. In SECAM mode, the chroma trap frequency is dynamically steered to follow the instantaneous frequency of the chroma.

Then, another transversal filter provides luma peaking, which is also active in S–VHS mode. The high frequency luma may be peaked (at about 3.0 MHz with the 17.7 MHz crystal, and 2.4 MHz with the 14.3 MHz crystal) in 7 steps up to a maximum of 8.5 dB, by a control word from the MCU.

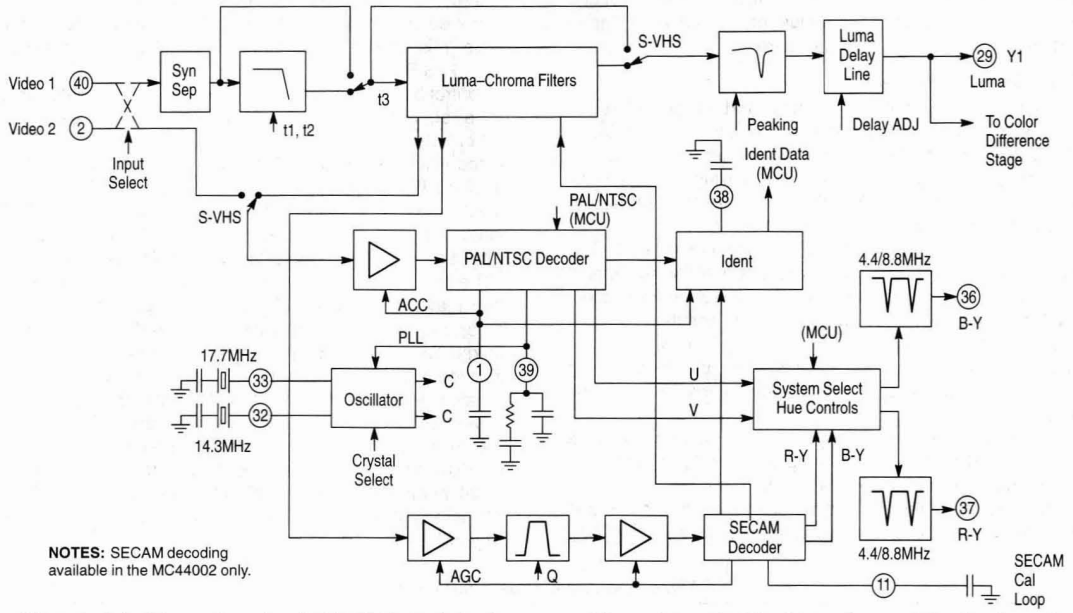
Another control word is used to trim the delay in the luma channel. Five steps of 56 ns (70 ns with the 14.3 MHz crystal) are possible, giving a total programmable delay of 280 ns. Steps 6 and 7 are used in S–VHS mode. The resulting processed luma signal then proceeds to the color difference section after being low–pass filtered by an active filter to remove components of the crystal frequency, and twice that frequency. The luma component (Y1) is made available at Pin 29 for use with auxiliary external functions, as well as testing.

When in the S–VHS mode, the S–VHS control bit controls the signal paths. The luma signal bypasses the first section of the luma channel, which contains the chroma trap. The S–VHS chroma is passed directly to the PAL/NTSC decoder without further filtering.

As all the delay and filter responses are determined by the crystal, they automatically commute to the new standard when the crystal is changed over. Thus, when the 14.3 MHz clock is being used, the chroma trap moves to 3.58 MHz.

The filtered PAL/NTSC and SECAM chroma signals are decoded by their respective circuits. The PAL/NTSC decoder employs a conventional design, using ACC action for gain control and the common double balanced multipliers to retrieve the color difference signals. The SECAM decoder is discussed in a separate subsection.

**Figure 8. Chroma Decoder**




**NOTES:** SECAM decoding available in the MC44002 only.

The actual decision as to a signal's identity is made by the MCU based on data provided by 3 flags returned to it, namely: ACC Active, PAL Identified, and SECAM Identified.

Control bits SSA–SSD must be sent to set the decoder to the correct standard.

This allows a maximum of flexibility, since the software may be written to accommodate many different sets of circumstances. For example, channel information could be taken into account if certain channels always carry signals in the same standard. Alternatively, if one standard is never going to be received, the software can be adapted to this circumstance. If none of the flags are on, color killing can be implemented by the MCU. This occurs if the net Ident Signal is too low, or if the ACC circuit is inactive due to too low a signal level.

The demodulated color difference signals now enter the Hue control section, where selection is made between PAL/NTSC and SECAM outputs. The Hue control is simply realized by altering the amplitudes of both color difference signals together. Hue control is only a requirement in NTSC mode and would not normally be used for other standards. The function is usually carried out prior to demodulation of the chroma by shifting the phase of the subcarrier reference, causing decoding to take place along different axes. In the MC44002/7, Hue control is performed on the already demodulated color difference signals. A proportion of the R-Y signal is added or subtracted to the B-Y signal and vice-versa. This has the same effect as altering the reference phase. If desired, the MC44002/7 can apply the Hue control to simple PAL signals.

After manipulation by the Saturation and Hue controls, the color difference signals are finally filtered to reduce any remaining subcarrier and multiplier products. Before leaving the chip at Pins 36 and 37, the signals are blanked during line and frame intervals. The 64 µs chroma delay line is carried out by a companion device, the MC44140.

**SECAM Decoder (MC44002 only)**

The SECAM signal from the high-pass filter enters tightly controlled AGC amplifiers wrapped around a cloche filter which is a sampled recursive type, with the AGC derived from a signal squarer. Next, the signal is blanked during the calibration gate period and a reference 4.43 MHz is inserted during this time. The SECAM signal is then passed through a limiter.

The frequency demodulator function is carried out by a frequency-locked-loop (F.L.L.). This consists of three components: a tracking filter, a phase detector and a loop filter. The center frequency of the tracking filter depends on three factors: internal R-C product, ADJUST voltage, and TUNING voltage. The tracking filter is dynamically tuned by the TUNING feedback from the loop-filter forming the F.L.L. The ADJUST control calibrates the F.L.L. and compensates for variations in the R-C product. After the F.L.L., the color difference signals are passed to another block where several functions are carried out. The signals are de-emphasized and outputs are provided to the Ident section. Another function of this section is to generate the $I_{COMP}$ signal used for calibrating the F.L.L. This signal is blanked during the H-IG period to ensure that (R-Y) and (B-Y) output signals have a clean dc level for clamping purposes.

In addition, components are added to compensate for the R-C product, and tuning offsets are introduced during the active lines for F0R/F0B.

Calibration of the F.L.L. takes place during every field blanking interval, starting from field retrace and ending just before the SECAM vertical Ident sequence (bottles). The calibration current $I_{CAL}$ is derived from $I_{COMP}$ during the

calibration gate (CAL) and integrated by an external capacitor on Pin 11. The resulting voltage $V_{EXT}$ is then transformed to generate the ADJUST control voltage removing from the loop range most of the variations due to internal RC products and temperature.

**Color Difference Stages**

This stage accepts luminance and color difference signals, together with external R,G,B and Fast Commutation inputs and carries out various functions on them, including clamping, blanking, switching and matrixing. The outputs, consisting of processed R,G,B signals, are then passed to the Auto Gray Scale section.

A block diagram of this stage is shown in Figure 10. The Y2, R-Y, B-Y together with R, G and B are all external inputs to the chip. The Y1 signal comes from the decoder section. Each of the signals is back-porch clamped and then blanked. The Y2 and R,G,B inputs have their own simple sync separators, the output from which may be used as the primary synchronization for the chip by means of commands from the MCU.

The Fast Commutation is an active high input used to drive a high speed switch; for switching between the Y and color difference inputs and the R,G,B (text) inputs.

After blanking, the Y1 and Y2 channels go to the Luma Selector which is controlled by means of 2 bits from the MCU. From here the selected luma signal goes to the RGB matrix. The two color difference signals pass through the saturation control. From here they go to a matrix in which G-Y is generated from the R-Y and B-Y, and lastly, to another matrix where Y is added to the three color difference signals to derive R,G,B.

Control bits (via the $I^2C$ bus) allow the matrix coefficients to be adjusted in order to suit different requirements, particularly in NTSC. Table 1 shows the theoretical demodulation angles and amplitudes and the corresponding matrix coefficient values for each of the 4 selectable modes. (The A mode corresponds to the standard PAL/SECAM/NTSC mode). Although primarily intended for NTSC, this feature can also act on PAL/SECAM or external RGB signals.

The R,G,B inputs may take one of two different paths. They may either go straight to the output without further processing, or via a separate matrix and the saturation control. The path taken is controlled in software. When the latter route is selected, the R,G,B signals undergo a matrix operation to derive Y. From this, R-Y and B-Y are easily derived by subtraction from R and B; the derived color difference signals are then subjected to saturation control. This extra circuitry allows another feature to be added to the TV set, namely the ability to adjust the color saturation of the RGB inputs. After the saturation control the derived signals are processed as before.

**Table 1. Matrix Modes Coefficients**

| | A | B | C | C |
|---|---|---|---|---|
| RR | 1.0 | 1.577 | 1.539 | 1.556 |
| RB | 0 | –0.156 | –0.248 | –0.251 |
| GR | –0.513 | –0.443 | –0.462 | –0.504 |
| GB | –0.187 | –0.168 | –0.150 | –0.125 |
| BB | 1.0 | 1.0 | 1.0 | 1.0 |
| BR | 0 | 0 | 0 | 0 |
| Rm | 0.562 | 0.9 | 0.9 | 0.91 |
| Gm | 0.344 | 0.3 | 0.3 | 0.31 |
| Ra | 90 | 100 | 106 | 106 |
| Ga | 237 | 236 | 240 | 246 |

**NOTE:** BB = Gain of $(B_{out}/(B–Y)_{in})$ = 1 (reference). BR = Gain of $(B_{out}/(R–Y)_{in})$ = 0 (theoretically).

**Figure 9. SECAM Decoder (MC44002 only)**

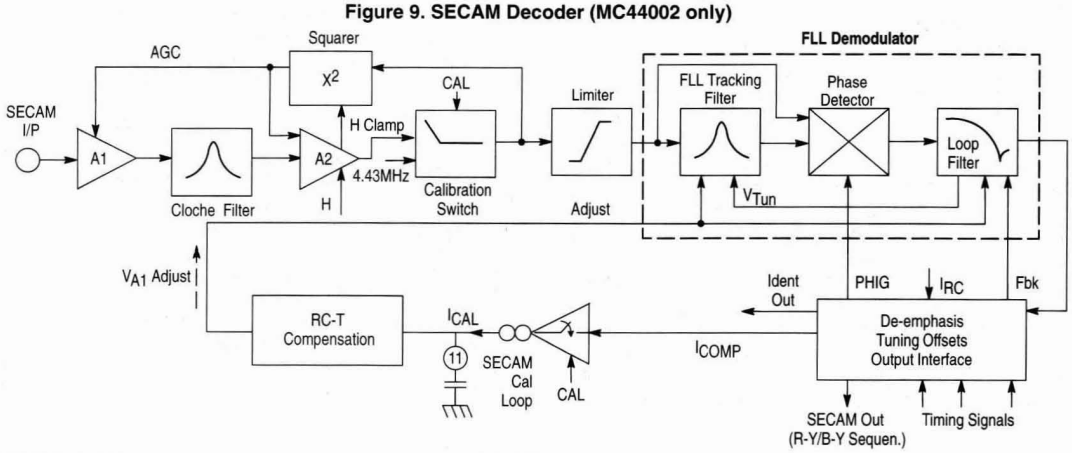
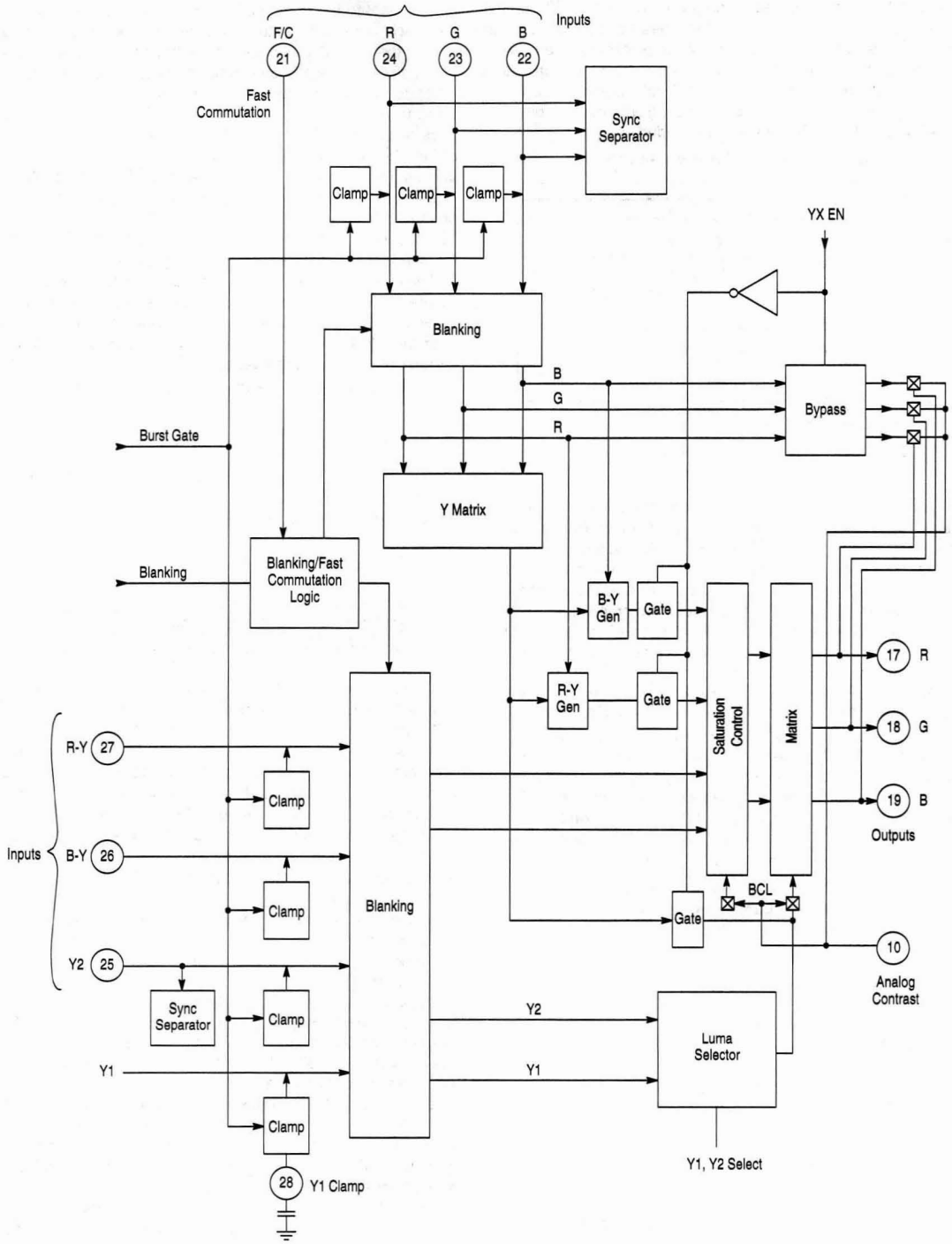


**Figure 10. Color Difference Stages**



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In order to implement automatic beam current limiting (BCL), the possibility of fast contrast reduction has been added. For normal operation, the Contrast control is achieved by auto grey scale output loops and is I²C bus controlled (see Section 4). In the case of excess beam current, this control is not fast enough to protect the tube and power supply stages. It is now possible, by acting on the Pin 10 voltage, to reduce the contrast about 12 dB by reducing the luma gain and saturation. In the case of direct RGB mode, the RGB gains are also reduced.

**Figure 11. Typical Contrast Reduction**

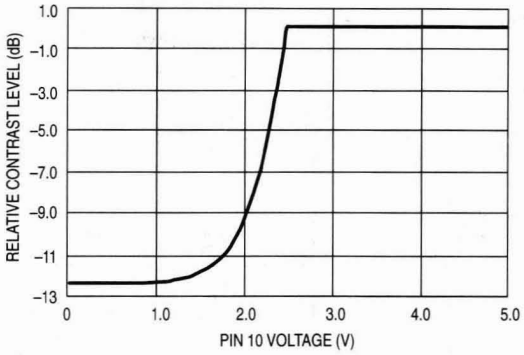
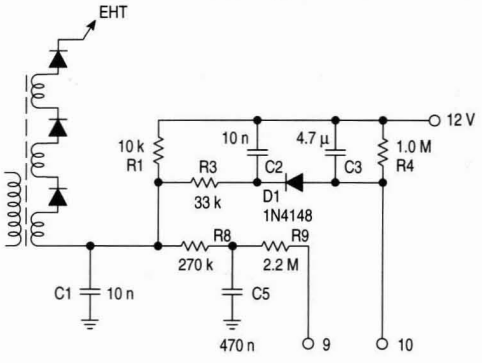



Figure 11 is showing the typical analog CONTRAST reduction possible as a function of the voltage on Pin 10. Two solutions are possible for obtaining the BCL function:

*1st solution:* A measure of the average and/or peak beam current is applied to Pin 10, which causes a reduction of the RGB drive levels to the high voltage video amplifiers. In this case, no software control is required, but variations in color balance and saturation may be observed. A typical application is shown in Figure 12.

*2nd solution:* The beam current flags are read and acted on by the MCU, which reduces the I²C bus CONTRAST control to maintain the average beam current below the desired level. In the case of rapid and extreme beam current changes (black to white picture at high contrast level), the circuit of Figure 12 may be used as a fast aging protection while the MCU is reducing the CONTRAST through I²C bus. The average of this method is to make any color balance/saturation variation only transient.

**Figure 12. Automatic Beam Current Limiter Application**

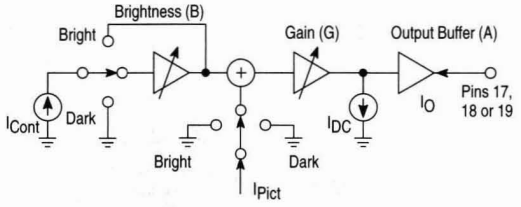



**Auto Gray Scale Control Loops**

This section supplies current drives to the RGB cathode amplifiers and receives a signal feedback from them, proportional to the combined cathode currents. The current feedback is used to establish a set of feedback loops to control the dc level of the cathode voltage (cut–off), and gain of the signal at the cathode (white balance). There are three loops to control the dark currents dark loops and another three to control the gains bright loops. The system uses 3 lines at the end of the vertical suppression period and just before the beginning of the picture for sampling the cathode current (i.e., one line for red, one for green and one for blue). The first half of reach line is used for adjusting the gain of the channel and is usually called the "bright" adjustment period. The second half of the line is used for adjusting the dc level of the channel and is called the "dark" adjustment.

The theoretical circuit diagram for one channel is shown in Figure 13 along with the basic equations. The dc level (Idc) and gain (G) are both controlled by 7 bit DACs which receive data directly from latches in which the required values are stored between sampling periods.

**Figure 13. Bright/Dark Current Control**




Picture Output Current: $I_{O(Pict)} = A \times [I_{DC} = G \times ((B \times I_{Cont}) + I_{Pict})]$
Dark Sample Output Current: $I_{O(dk)} = A \times I_{DC}$
Bright Sample Output Current: $I_{O(br)} = I_{O(dk)} - A \times G \times I_{Cont}$
Black Level Output Current: $I_{O(bk)} = I_{O(dk)} - B \times A \times G \times I_{Cont}$
$= I_{O(dk)} \times B \times [I_{O(dk)} - I_{O(br)}]$

A block diagram of the complete system is illustrated in Figure 16. Data words from the MCU which represent the RGB color temperatures selected at the factory, are stored in Latches 1,2,3 and D/A converted by DAC1,2,3 to reference currents. During the bright adjustment period, a reference current pulse, whose amplitude depends on the Contrast setting, is output to the cathode of the tube. The gain control is adjusted to bring the feedback current to the same value as the bright reference current, which is defined by the color intensity setting of the output considered. The currents must match each other. If not, a current will flow in resistor R producing an error voltage. This is then buffered into comparators Comp1, 2 and is compared with voltage references $V_{ref1}$ and $V_{ref2}$. If the error voltage is greater than $V_{ref1}$, Comp1 causes the counter to count up. If the error voltage is less than $V_{ref2}$, Comp2 sends a count-down command. In this way, a "deadband" is set up to prevent the outputs from continuously changing. With the color intensity DAC set to about $32_d$, the bright cathode current is 100 µA (10 times the dark current).

During Load the contents of the counter are loaded into Latch 6 (for red dc) and then D/A converted. The resulting dc current is then applied as an offset to the red output amplifier, completing the loop. During the dark adjustment period, the same intensity data is used but divided by a common factor (typically 10). A black level reference pulse is applied and the feedback loop adjusts the dc levels of the cathode to obtain a set of cathode currents equal to the dark reference currents

(10 μA). Therefore, the image color will always be adjusted to match the dark level color, i.e. grey scale tracking is ensured.

The Load/Backload sequencer is used to control which latch is being addressed at any given time by means of the timing signals input to it. The backload command sends the data from the appropriate latch to the Up/Down Counter, ready to be modified if necessary.

The Brightness control is affected by simply changing the dc pedestal of all three drives by the same amount, and does not form part of the feedback loop. The Contrast is adjusted to a set of values dependent on the level of the bright pulse applied during the set–up period. This level is set by a control word from the MCU. Once the loops have stabilized under normal working conditions, they may be deactivated by means of a control bit from the MCU. When, however, any change is made to either contrast or RGB intensity, the loops must be reactivated. For normal operation, it is not necessary to deactivate the bright loops.

Increasing the RGB intensity values will cause the Black–to–White cathode voltage amplitude to increase for a given Contrast setting. The White balance can therefore be set by adjusting the relative values of R, G and B intensity. An extra loop has been included via Latch 4 and DAC 4, which operates during the field flyback time to compensate for offsets within the loop. This has the effect of counteracting any input offset from the Buffer/Amp and will also compensate for cathode leakage should this be needed.

A second output of the reference currents from the RGB DACs are used to compare with preset limits, to ensure that the loops are working within their range of control. Should the limits be exceeded in either direction, flags are returned to the MCU to request that the G2 control be adjusted up or down as appropriate. Once set–up, the servo loops maintain the same conditions throughout the life of the TV.

**Horizontal Timebase**

The horizontal timebase consists of a PLL which locks up to the incoming horizontal sync, and a phase detector and shifter whose purpose is to maintain the H-Drive in phase with the line flyback pulse.

Because of on-chip component tolerances, the free-running oscillator frequency cannot be set more accurately than ± 40%; this range would be too much for the line output stage to cope with. For this reason the free-running frequency is calibrated periodically by other means. During startup and whenever there is a channel change, the phase detector is disconnected from the VCO for 2 lines during the blanking interval. A block diagram of the line timebase is given in Figure 14. The calibration loop consists of a frequency comparator driving an Up/Down Counter. The count is D/A converted to give a dc bias which is used to correct a 1.0 MHz VCO. The 1.0 MHz is divided by 64 to give line frequency and this is returned to the frequency comparator. This compares Fh from the VCO with a reference derived from dividing down the subcarrier frequency. Any difference in frequency will result in an output from the comparator, causing the counter to count up or down; and thus closing the loop. Since the horizontal oscillator is quite stable, this calibration does not need to be carried out very often. After switch–on, the calibration loop need only be enabled when the timebase goes out of lock.

A Coincidence Detector looks at the PLL Fh and compares it with the incoming H-sync. If they are not in lock, a flag is returned to the MCU. To allow for use with VCRs, the gain of the phase detector may be switched by means of commands from the MCU (bits HGAIN1 and HGAIN2). The gain of the phase detector is switched to the maximum value at the end of the vertical sync pulse and then reduced to the selected value after about 11 lines. This allows the horizontal timebase to rapidly compensate any horizontal phase jump (e.g. with a VCR) during the vertical blanking period, thus avoiding bending at the top of the picture.

Twice line frequency is output from the PLL which may be divided by either 1 or 2 depending on the command of the MCU. The x2 Fh will be used with Feature Boxes. The phase of the Fh and flyback pulses are compared in a phase detector, whose output drives a phase shifter. A 6-bit control word and D/A converter are used to apply an offset to the phase detector giving a horizontal phase shift control.

The presence of the horizontal flyback pulse is detected; if it is missing a warning flag is sent back to the MCU which can take appropriate action.

**Vertical Timebase**

The vertical timebase consists of two sections; a digital section which includes a vertical sync separator and standard recognition; and an analog section which generates a vertical ramp which may be modified under MCU control to allow for geometrical adjustments. A parabola is also generated and may be used for pin-cushion (E-W) correction and width control (see Figure 15).

In the digital section, the MC44002/7 uses a video sync separator which works using feedback, such that the threshold level of a comparator (slice level) is always maintained at the center of the sync pulse. Sync from any of the auxiliary inputs may also be used. The composite sync is fed to a vertical sync separator, where vertical sync is derived. This consists of a comparator, up/down counter and decoder. The counter counts up when sync is high, and down when sync is low. The output of the decoder is compared with a threshold level, the threshold only being reached with a high count during the broad pulses in the field interval.

When "Auto Countdown" is selected, the vertical timebase in fact starts off in the "Injection Lock" mode. This means that the timebase locks immediately to the first signal received, in exactly the same way as an old type injection locked timebase. A coincidence detector looks for counts of the right number (525 e.g.), and causes a 4 bit counter to count up. When there are 8 consecutive coincidences, the vertical countdown is engaged, and the MSB of the counter is brought out to set the flag. Similarly, non–coincidence, which will occur if synchronizing pulses are missing or in the wrong place, or if there is noise on the signals, causes the counter to count down. When the count goes back to zero, after 8 noncoincidences, the timebase automatically reverts to "Injection Lock" mode.

If it is known that lock will be lost (e.g., channel change), it is possible to jump straight into Injection Lock mode and not have to wait for the 8 consecutive non-coincidences. In this way the new channel will be captured rapidly. Once locked on to the new channel, "auto countdown" is then reselected by the MCU.

Under some conditions such as some VCRs in Search mode, it is possible to get signals having an incorrect number of lines, meaning that the countdown flag will go off because of successive non-coincidences. In these circumstances, if "auto countdown" is selected, the timebase will automatically lock to the signal in the Injection Lock mode. The fact that the

flag is effectively saying that the vertical timebase is out of lock need not be a cause for major concern, since the horizontal timebase will still be locked to the signal, and has its own flag – "Horizontal out of lock". The vertical countdown and horizontal lock flags both perform an independent test for the presence of a valid signal. A logical OR function can be performed on the two flags, such that if either are present then by definition a valid signal is present.

The vertical oscillator has end-stops set at two line-count decodes as given below:

50 x 625 / 740 = 42.2 Hz (min)

50 x 625 / 448 = 69.8 Hz (max)

These figures assume that the horizontal timebase is running at 15,625 Hz. When the vertical timebase is in Injection Lock mode, the line counter reset is inhibited so that it ignores any sync pulses before a count of 448 is reached. This prevents any possible attempted synchronization in the middle of the picture. If the count reaches 740 lines, then there is an automatic reset which effectively sets the lower frequency limit. The choice of these limits is a compromise between a wide window for rapid signal capture and a narrow window for good noise immunity.

It is also possible to run the timebase in 2.0 V mode as there are decodes for 100 Hz (2 x 50 Hz) operation with upper and lower limits in proportion. This is, of course, intended to be used in conjunction with field and frame memory stores. The similar decodes which would be necessary to allow 120 Hz (2 x 60 Hz) operation have not, for the present, been implemented. Finally, the timebase can be forced into a count of either 625 or 525 by commands from the MCU; in this mode the input signal, if present, is ignored completely. If there is no signal present save for noise, then this feature can be used to obtain a stable raster.

In the analog section, an adjustable current source is used to charge an external capacitor at Pin 6 to generate a vertical ramp. The amplitude of the ramp is varied according to the current source (Height), and is automatically adapted when the 525 standard is recognized by multiplying by 1.2. The Linearity control is achieved by squaring the ramp and either adding or subtracting a portion of it to the main linear current. In addition, a correction current, depending on the level of anode current, is applied in the sense of oppose a change of picture height with EHT (Breathing).

The final ramp with corrections added is then passed to a driver/amplifier and is output at Pin 7. The vertical ramp can be used to drive a separate vertical deflection power circuit with local feedback control. Vertical "S" Correction will then be made using fixed components within the feedback loop of the power op amp. The vertical position can be adjusted under MCU control – this is achieved by varying the dc output level at Pin 7. The vertical amplitude can be reduced to 75% of its original value (bit VDI) to make possible the display of a 16:9 picture on a 4:3 screen.

The reference ramp is squared to provide a pin-cushion correction parabola, developed across an external resistor at Pin 8. The parabola itself is squared, giving an independent fourth order term (Corner Correction) whose level can also be varied; this is then added as a further modifying term to the E-W output. This latter correction is used for obtaining good corner geometry with flat-square tubes. A variable dc current is added to the parabola to effect a width control. Using a suitable power amplifier and a diode-modulator in the line output stage, the parabola may be used for E-W correction and dynamic width control. A further control is provided to shift the center point of the parabola up and down the screen (Parabola Tilt).

All of the vertical and horizontal signals are adjustable via 6-bit words from the MCU, and stored in latches. The adjustment controls available are:

Vertical Amplitude/Linearity/Breathing Correction/Position
Parabola (E-W) Amplitude/Horizontal Amplitude/
Corner Correction, and Parabola Tilt

The Anode Current Sense at Pin 9 is also used as a beam current monitor. Two thresholds may be set, by the manufacturer, using external components. The first threshold sets a flag to the processor if beam current becomes excessive. The MCU could, e.g., reduce brightness and/or contrast to alleviate the condition. The second threshold sets a flag warning of an overload condition where the CRT phosphor could be damaged. If such a condition were to arise, the processor would be programmed to shut down the PSU.

The vertical blanking lines may be selected by means of a bit from the MCU for either the 525 or 625 standard. The interlace may also be suppressed again under the control of the processor (bits ICI, IFI).

**Figure 14. Horizontal Timebase**

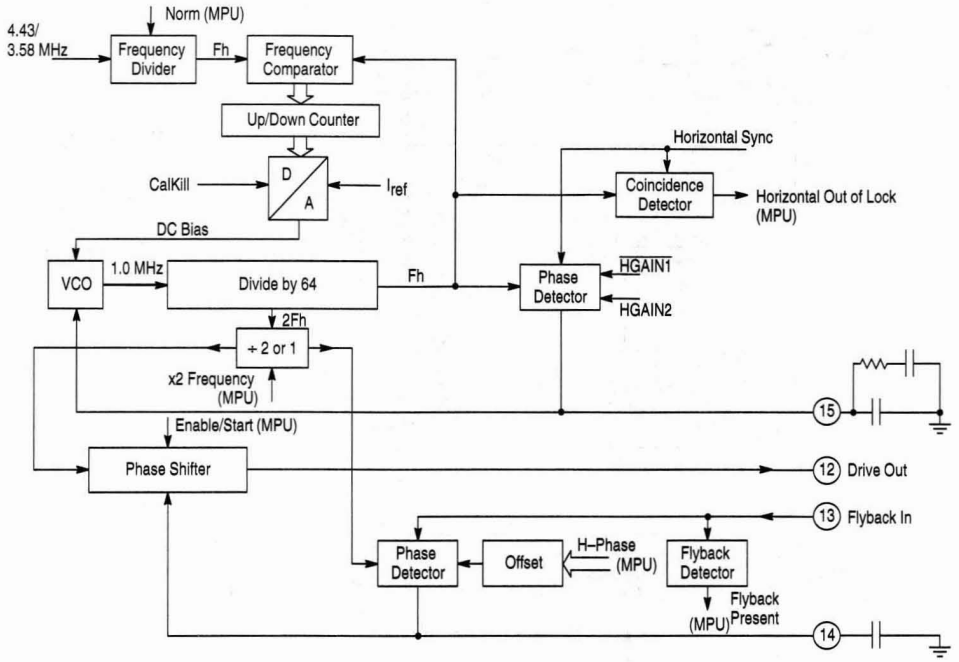



**Figure 15. Vertical Timebase**

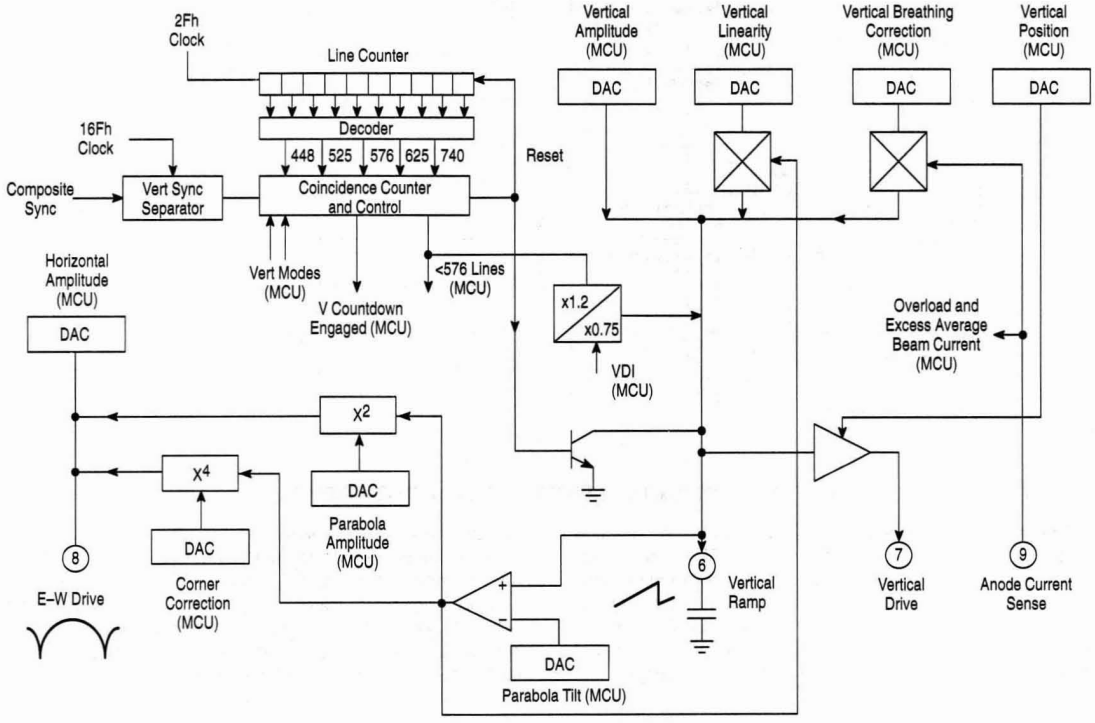
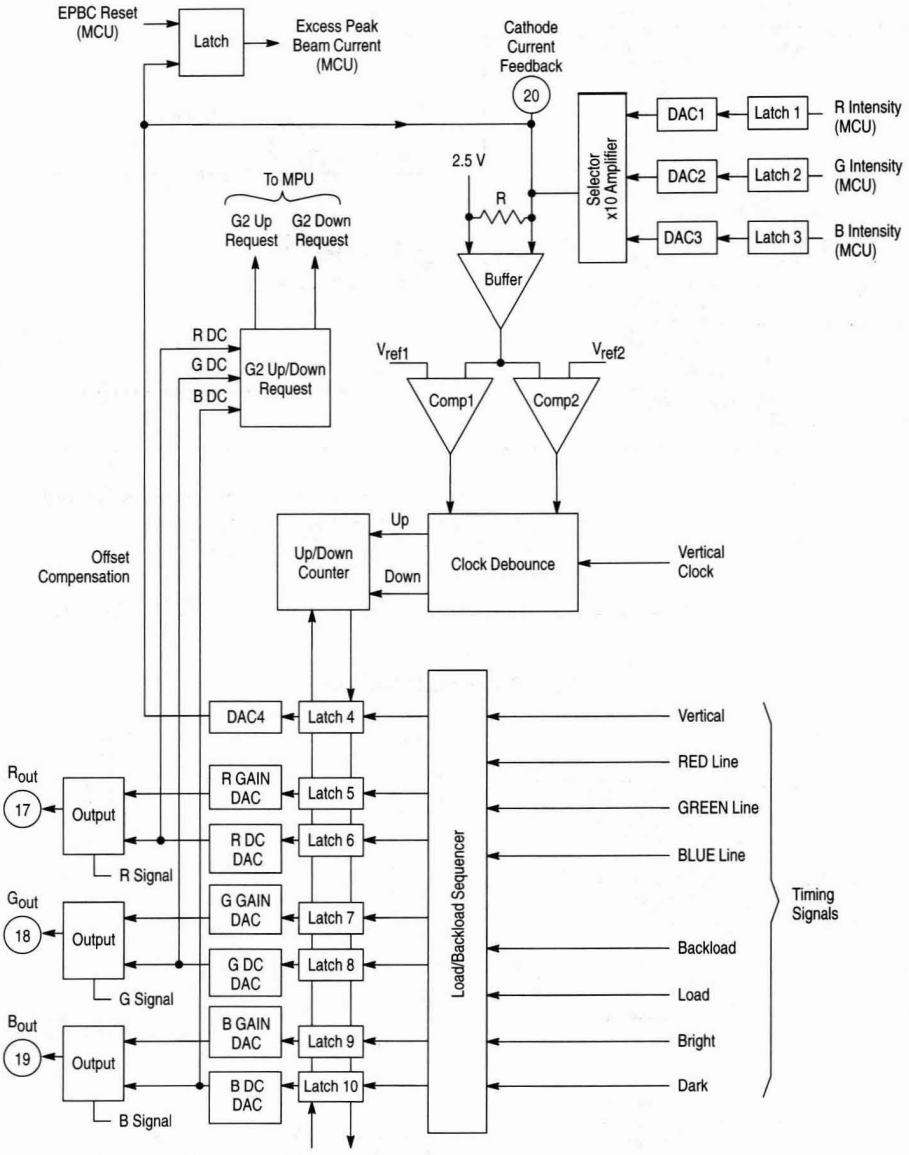


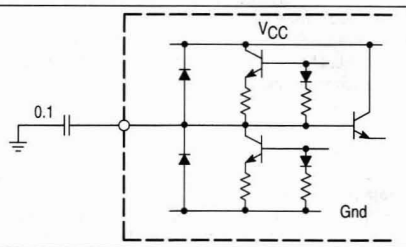
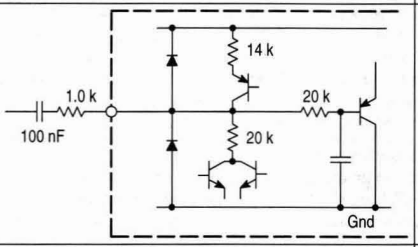
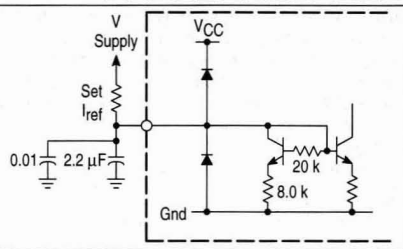
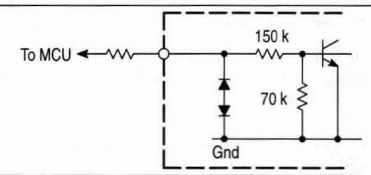
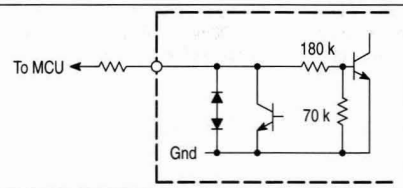
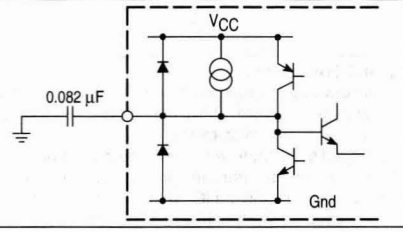
**Figure 16. Auto Gray Scale Control Loops**




## PIN FUNCTION AND EXTERNAL CIRCUIT REQUIREMENTS

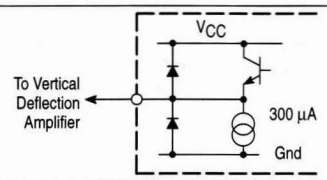
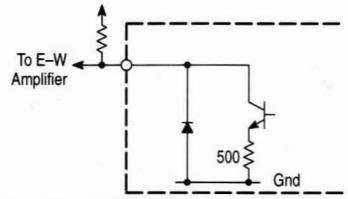
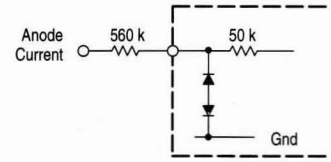
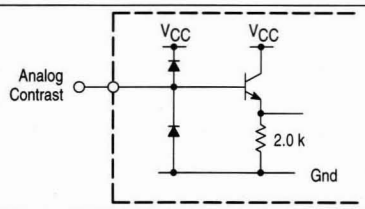
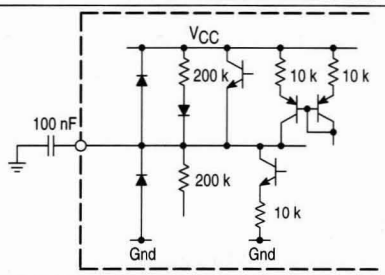
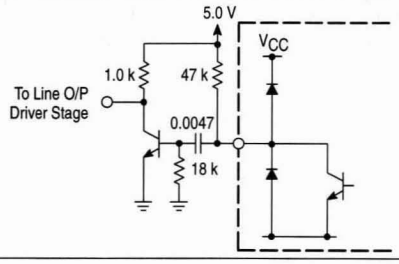
The following section describes the purpose and function of each of the 40 pins on the MC44002/7. There is also an explanation of the external circuit component requirements for a practical application; a diagram of the small signal circuit will be found in Figure 17. One of the primary design aims for the MC44002/7 was to use the minimum number of external components, and where these are necessary, to employ low cost and easily obtainable standard types. Thus for example, as all the video signal filtering is carried out on the IC, there are no coils required whatsoever. The most common requirement is for ac coupling capacitors which are far too big to be integrated onto the chip. The time constants on certain pins are deliberately determined by external components to facilitate testing and for fine tuning the performance.

## PIN FUNCTION DESCRIPTION

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 1 |  | **ACC**<br>External Filter used by ACC section. A single capacitor, that does not have a critical value, typically 0.01 µF, filters the feedback loop of the chroma automatic gain control amplifier. |
| 2<br>40 |  | **Video Input 1 (Pin 40) and 2 (Pin 2)**<br>Video inputs (Pin 2 = Video 2; Pin 40 = Video1); Intended for a nominal 1.0 Vpp input level of composite video. Separate luma and chroma components may also be used with these input pins for S–VHS. The external circuit requirement is for a coupling capacitor of 0.01 µF and a series resistance not exceeding 1.0 kΩ. The input selection and adaptation for Y and C is carried out in software. |
| 3 |  | **Reference Current**<br>Master reference current used throughout the IC. This is programmed by means of an external pull–up resistor, as on–board resistors are not sufficiently accurate. The designated current is 70 µA. This pin should be very well de–coupled to ground to avoid picking up interference from the nearby I²C bus inputs. Nominal voltage at the pin is 1.3 V. |
| 4 |  | **I²C Clock**<br>I²C bus clock input. This input can be taken straight into the IC, but in a real TV application it may be prudent to fit a series current limiting resistor near the pin in case of flash–over. A single pull–up resistor to 5.0 V is required. Although its value is associated with the µP, taking into account system capacitance at high data rates, a value of 4.7 kΩ, giving optimal performance, is recommended. |
| 5 |  | **I²C Data**<br>I²C data input. Comments above for Pin 4 also apply to this pin. |
| 6 |  | **Vertical Ramp**<br>A current is used to charge an external capacitor connected to this pin, developing a voltage sawtooth with a field period. The capacitor value determines the ramp amplitude. 82 nF is the more convenient value for symmetrical, linearity and parabola tilt adjustments. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 7 |  | **Vertical Drive**<br>The sawtooth derived on Pin 6 is used to drive an external power amplifier vertical output stage. The amplitude, linearity and position of the output ramp are adjustable via the MCU. |
| 8 |  | **Parabola (E–W) Drive**<br>An inverted parabolic waveform derived by squaring the vertical ramp is used to drive an external power amplifier. In sets fitted with a diode modulator type line output stage, this provides width control and pin–cushion correction. The parabola is squared again to give a fourth order correction term required for flat square tubes. The E–W amplitude, dc level, tilt and corner correction are all adjustable by means of the MCU. This is a current output and may be used, for example, to drive the virtual ground of an external power amplifier |
| 9 |  | **Anode Current**<br>Used as an anode current monitor whose purpose is to: (1) Provide E.H.T. compensation (anti–breathing) for the vertical ramp; and (2) provide warning of excessive and overload beam current conditions.<br>The pin is connected via about 560 kΩ series resistor to the bottom of the E.H.T. overwinding. Therefore, increasing beam current will pull the voltage on this pin more negative. This change is sensed within the chip and used to apply a correction to the ramp and parabola amplitudes. With large beam currents, thresholds at $+V_{be}$ and $-2.0\ V_{be}$ set off warning flags to the MCU, which then has to take the appropriate action. The anode current levels at which these thresholds are reached are set up using fixed external resistors. |
| 10 |  | **Anode Contrast**<br>This pin is used as an Analog Contrast monitor, allowing fast Beam Current Limiting (BCL). The fast BCL is controlled by Pin 10 voltage, which decreases with the contrast reduction (see typical curve).<br>Above 2.5 V on the pin, the contrast remains maximum. Below 2.5, the contrast is reduced by about 12 dB, which is reached at about 1.0 V. |
| 11 |  | **SECAM Calibration Loop**<br>This pin is used for the storage capacitor of the analog SECAM calibration loop (typically 100 nF). The capacitor is required regardless of whether or not SECAM will be decoded. |
| 12 |  | **Horizontal Drive Output**<br>Horizontal drive pulses having an approximately even mark–to–space ratio emerge from this pin. This is an open–collector output which can sink up to 10 mA. However, taking this much current is not recommended since there is no separate ground pin available which may be connected near the line output stage; noise could be injected into the signal ground on the IC. Therefore, with a transformer driven line output stage, this output has been designed to be used with an extra external transistor inverter between the IC and the line driver. The transistor is open during the period when the line deflection transistor should be conducting. |

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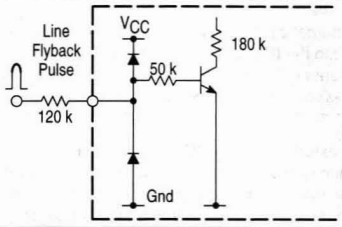
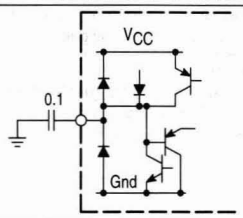
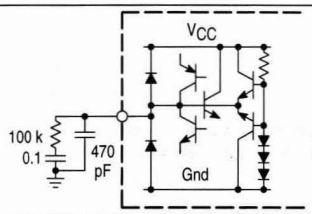
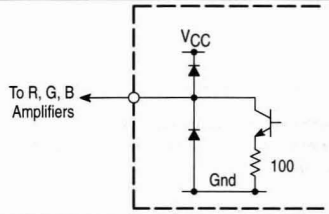
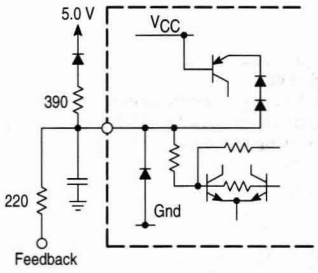
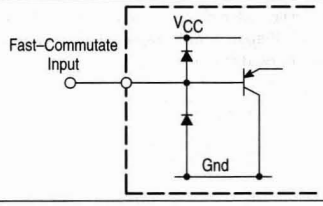
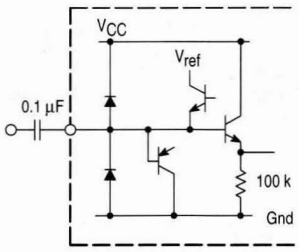
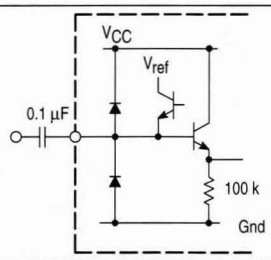
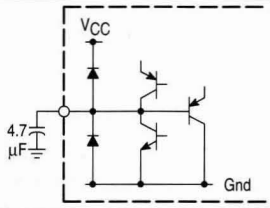
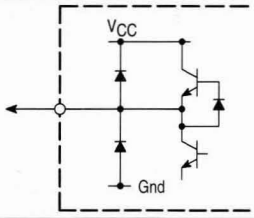
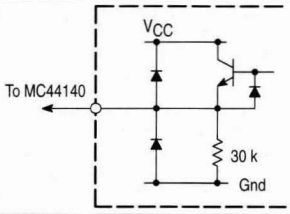
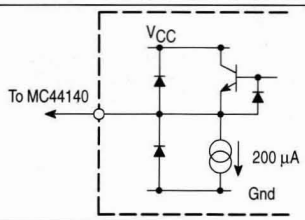
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 13 |  | **Horizontal Flyback Input**<br>Flyback sensing input taken from the line output transformer. These pulses are used by the 2nd horizontal loop for H–Phase control. A positive going pulse from 0 to 5.0 V amplitude is needed for correct operation. The internal impedance of the pin is about 50 kΩ and an external attenuating series resistor of around 120 kΩ will also be needed. |
| 14 |  | **Horizontal Loop 2 Filter**<br>Components at this pin filter the output of the phase detector in the 2nd horizontal loop. A simple external filter consisting of a 0.1 µF capacitor is required. |
| 15 |  | **Horizontal Loop 1 Filter**<br>Horizontal PLL loop time constant. Components at this pin filter the output of the phase detector is in the 1st horizontal loop. The value of RC time constant is selected with external components to give a smooth recovery after the field interval disturbance and to ensure optimum performances in the presence of noise. |
| 17<br>18<br>19 |  | **RGB Outputs**<br>The R, G and B drives are current rather than voltage due to the limited headroom available with the 5.0 V supply line. The outputs themselves consist of open–collector transistors and these are used to drive the virtual ground point of the high voltage cathode amplifiers |
| 20 |  | **Feedback**<br>Current feedback sense derived from the video output amplifiers. The currents from all three guns are summed together as each is driven sequentially with know current pulses during the field interval. This feedback is then compared with internally set–up references. A low value ceramic capacitor to ground may be fitted close to this pin to help stabilize the control loops.<br>A secondary function of this pin is for peak beam current limiting. When the feedback voltage during picture time becomes too great (i.e. too high beam current), a threshold at $V_{CC}$ + 3.0 $V_{be}$ is exceeded at which time a flag is sent to the MCU. The MCU then has to carry out the function of peak beam limiter by e.g. reducing contrast until the flag goes off. The threshold current is set externally with a fixed resistor value. |
| 21 |  | **Fast Commutate**<br>A very fast active high switch (transition time 10 ns) used with text on the RGB inputs, for overlaying text on picture. This hardware switch may be enabled and disabled in software. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 22<br>23<br>24 |  | **RGB Inputs**<br>These external input signals to the color difference stages are ac coupled into the IC via 0.1 µF capacitors. They have a clamp and sync separator. The inputs should be driven from a source of less than 1.0 kΩ output impedance with 700 mVpp signal levels. |
| 25 | | **Y2 Input**<br>Auxiliary external input to MC44002/7 which can be used in conjunction with auxiliary color difference inputs and/or as a sync input. The pin should be driven from a source of less than 1.0 kΩ output impedance with 700 mVpp luminance signal. The signal must be ac coupled via an external 0.1 µF coupling capacitor. Internal clamp and sync separator are provided. |
| 26<br>27 |  | **B–Y and R–Y Inputs**<br>Corrected color difference inputs from the MC44140. The signals are ac coupled via 0.1 µF capacitors and are clamped internally. The inputs should be driven from a source of less than 1.0 kΩ output impedance. |
| 28 |  | **YI Clamp**<br>External capacitor used by the circuit which clamps the Y1 signal output on Pin 29. A typical value is 4.7 µF. |
| 29 |  | **YI Output**<br>The luminance, after passing through the filter and delay line/peaking sections, is made available on this pin. It is also routed internally to the color difference stages. |
| 30 |  | **System Select**<br>A multilevel dc output controlled in software, which is used by the MC44140 for system selection. Please refer to separate functional description of the MC44140 chroma delay line. |
| 31 |  | **Sandcastle**<br>A special multilevel timing pulse derived in the MC44002/7 for use by the MC44140. Please refer to separate function description of the MC44140 chroma delay line. |

9

**PIN FUNCTION DESCRIPTION (continued)**

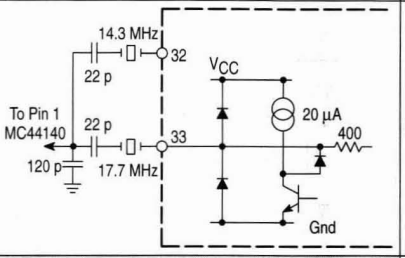
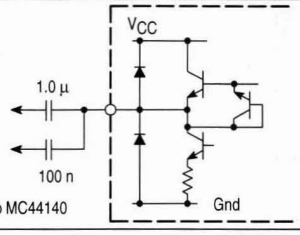
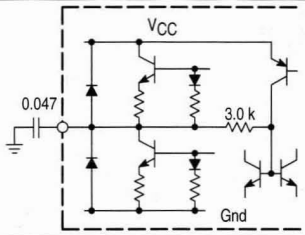
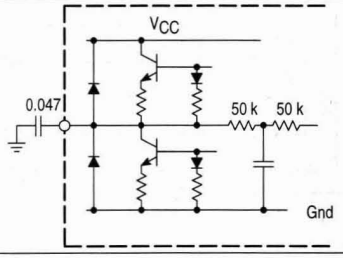
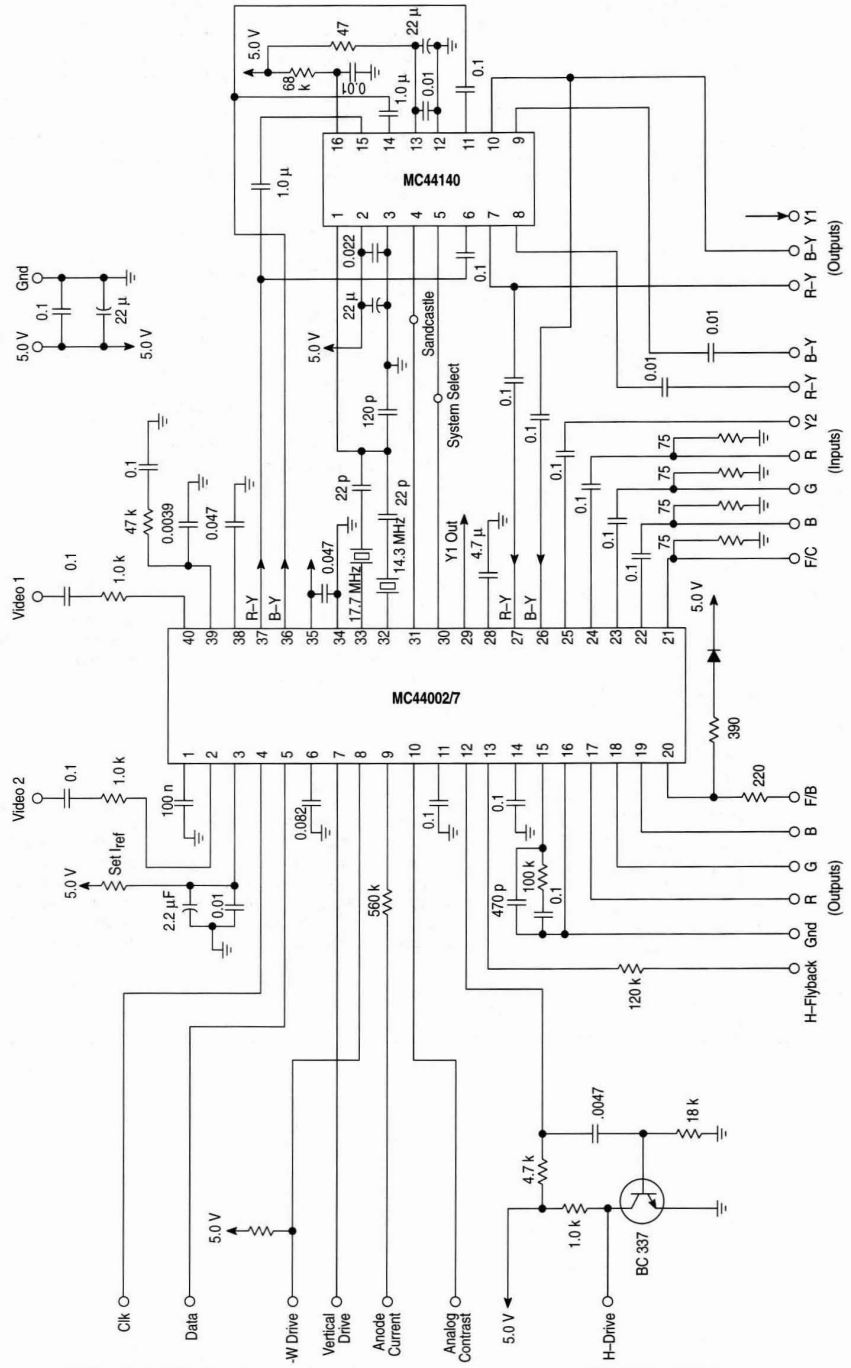
| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 32<br>33 |  | **Crystals (Respectively 14.3 MHz and 17.7 MHz)**<br>Drive for externally fitted crystal clock reference for PAL, SECAM or NTSC. Four times $F_{sc}$ is used. If the NTSC system is not going to be received, the 14.3 MHz crystal may be omitted. The crystal is parallel driven from a single pin and it requires a series load capacitance of appropriate value (usually 20 to 30 pF). Only crystals intended for VCO use should be fitted. The reference frequency is divided down in a capacitor chain to provide about 50 mV of clock reference for the MC44140.<br><br>Positions for Pins 32 and 33 are selected by software. |
| 34<br>35 | | **5.0 V Supply (35) and Ground (34)**<br>Supply line, nominally 5.0 V, requiring about 120 mA. The actual voltage should be in the range of 4.75 to 5.25 V for usable results. It is recommended to decouple the supply line using a small ceramic capacitor mounted close to the supply and ground pins. |
| 36<br>37 |  | **B–Y and R–Y Outputs**<br>Demodulated color difference outputs. These signals are ac coupled to the MC44140 for correction and delay with PAL and SECAM respectively. Signal level of about 1.4 Vpp may be expected on B–Y output when using a standard 75% color bars input video signal. |
| 38 |  | **Identification**<br>External filter used by R–Y identification circuit. The filter normally consists of a single capacitor whose value is a compromise between rapid identification and noise rejection. Experience has shown that 0.047 µF is a suitable value. |
| 39 |  | **Oscillator Loop Filter**<br>External time constant for chroma PLL. The crystal reference oscillator is phase locked to the incoming burst in PAL and NTSC. A low value ceramic capacitor, for good noise immunity, is normally placed in parallel with a much longer RC time constant. The PLL pull–in range is reduced when the time constant on the pin is made bigger, allowing this function to be optimized by the user. |

**Figure 17. Typical Application Circuit**



## SOFTWARE CONTROL FUNCTIONS

### General Description

As already related in the circuit description, the MC44002/7 has a memory of 18 bytes. All, except Sub-address 77 and 7F, use the 6 least significant bits as an analog control register with D/A converters (64 steps) within the memory section. The remaining bits are controlled individually for switching numerous functions. Table 2 gives a listing of all the memory registers and control bits. An explanation of the function of the 16 DACs is given below.

**Vertical Amplitude** – Changes the amplitude of the vertical ramp available on Pin 7.

**Vertical Breathing Correction** – A correction is applied to the vertical ramp amplitude in a sense opposite to the picture expansion and contraction produced by changes in beam current. This register alters the sensitivity of the beam current sensing and hence the size of correction applied for a given change in beam current.

**Parabola Amplitude** – Changes the amplitude of the E-W output parabola developed across an external pull-up resistor at Pin 8.

**Parabola Tilt** – Shifts the point of inflection of the E-W parabola from side to side along the time axis. Also known as *keystone correction.*

**Vertical Linearity** – The vertical ramp is multiplied by itself to give a squared term, a part of which is either added or subtracted to the linear ramp as determined by this register.

**Corner Correction** – An independent 4th order term which is subtracted from the E-W parabola to achieve correct geometry with flat square tubes.

**Horizontal Amplitude** – A variable dc offset applied to the E-W output parabola on Pin 8.

**Vertical Position** – Adjust the dc level of the vertical ramp on Pin 7, allowing vertical centering control.

**Horizontal Phase Control** – Applies a variable phase offset to the horizontal drive pulse at Pin 15 providing for a picture centering control.

**B, G, R Intensity** – These controls set up the current reference pulses used when sampling the beam current during field interval. The data is fixed by the TV manufacturer when setting up the White balance and the CRT for correct Gray Scale tracking.

(All the above registers are for use during the test and setting up procedures; the remaining 4 registers are also user controls.)

**Contrast** – During bright sample time during the field interval, this control varies the level of the current pulses injected into the R,G,B channels, so altering the picture contrast.

**Brightness** – A variable current pedestal which is added to the three drives during active picture time.

**Saturation** – A variable gain control for the two color difference signals.

**Hue** – Achieved by mixing a portion of one color difference signal into the other.

**Individually Adjustable Control Bits** – These consist of bits 7 and 6 of registers 77 through 88, as well as bits 0 to 5 of register 77 and bits 0 to 3 of register 7F. Some of these are used individually to control single functions requiring just on/off switching; and some are arranged into 2 or 3-bit words (e.g., luma peaking). A list of control words and truth tables for these may be found in Table 3.

**CA1, CB1** – Used to change the mode of operation of the vertical timebase to either injection lock or auto countdown, or to force it into 525 or 625 lines. Just prior to changing channel, the vertical timebase can be switched to injection lock mode and when a new channel is captured, the timebase is switched back to auto mode. In this way there is no delay in locking onto the new channel and hence no picture roll. If there is no valid signal being received, the display can be stabilized by forcing the timebase into 525 or 625 lines.

**IC1, IF1** – These bits are used to suppress the field interlace, which can be scanned in the nearest even or odd half line.

**$\overline{\text{HI}}$, $\overline{\text{VI}}$** – Selects the type of SECAM ident when operating in this mode. Either vertical ident bursts or horizontal ident can be selected individually, or ident can be taken from a combination of the two. In certain transmissions the vertical SECAM identification is not present (and sometimes replaced by other signals), so it is strongly recommended that only the horizontal identification be used. These bits must both be set to 1 when SECAM is not decoded (MC44002 and MC44007).

**SSA, SSB, SSC** – Used to set the color decoder and the dc level of the System Select output from the MC44002/7, Pin 30. This output is used by the MC44140 delay line in turn for changing between PAL, NTSC, SECAM and external modes of operation. In effect, the MC44140 is being controlled by the $I^2C$ bus via the MC44002/7.

**Table 2a. Register Memory Map**

| HEX Sub-address | MSB | Data Byte | | | | | | LSB |
|---|---|---|---|---|---|---|---|---|
| 77 | T3 | $\overline{\text{S-VHS}}$ | FSI | BAI | ICI | IFI | CBI | CAI |
| 78 | INTSEL | CALKILL | Vertical Amplitude | | | | | |
| 79 | $\overline{\text{HI}}$ | $\overline{\text{VI}}$ | Vertical Breathing Correction | | | | | |
| 7A | XS | SSD | Parabola Amplitude | | | | | |
| 7B | T1 | T2 | Parabola Tilt | | | | | |
| 7C | SSC | SSA | Vertical Linearity | | | | | |
| 7D | P1 | SSB | Corner Correction | | | | | |
| 7E | P3 | P2 | Horizontal Amplitude | | | | | |
| 7F | D3 | D1 | Reserved | | VDI | NT2 | NT1 | NT0 |
| 80 | $\overline{\text{D EN}}$ | D2 | Vertical Position | | | | | |
| 81 | Y2 EN | Y1 EN | Horizontal Phase Control | | | | | |
| 82 | $\overline{\text{TEST}}$ | YX EN | Blue Intensity | | | | | |
| 83 | Not Used | $\overline{\text{HGAIN1}}$ | Green Intensity | | | | | |
| 84 | HGAIN2 | NORM | Red Intensity | | | | | |
| 85 | BRI EN | 2x Fh | Contrast | | | | | |
| 86 | SSE | H EN | Brightness | | | | | |
| 87 | SS1 | Not Used | Saturation | | | | | |
| 88 | V1/V2 | SS2 | Hue | | | | | |
| 00 | | Dummy – If H EN, then starts H timebase | | | | | | |
| FF | | Dummy – Resets peak beam limit flag | | | | | | |

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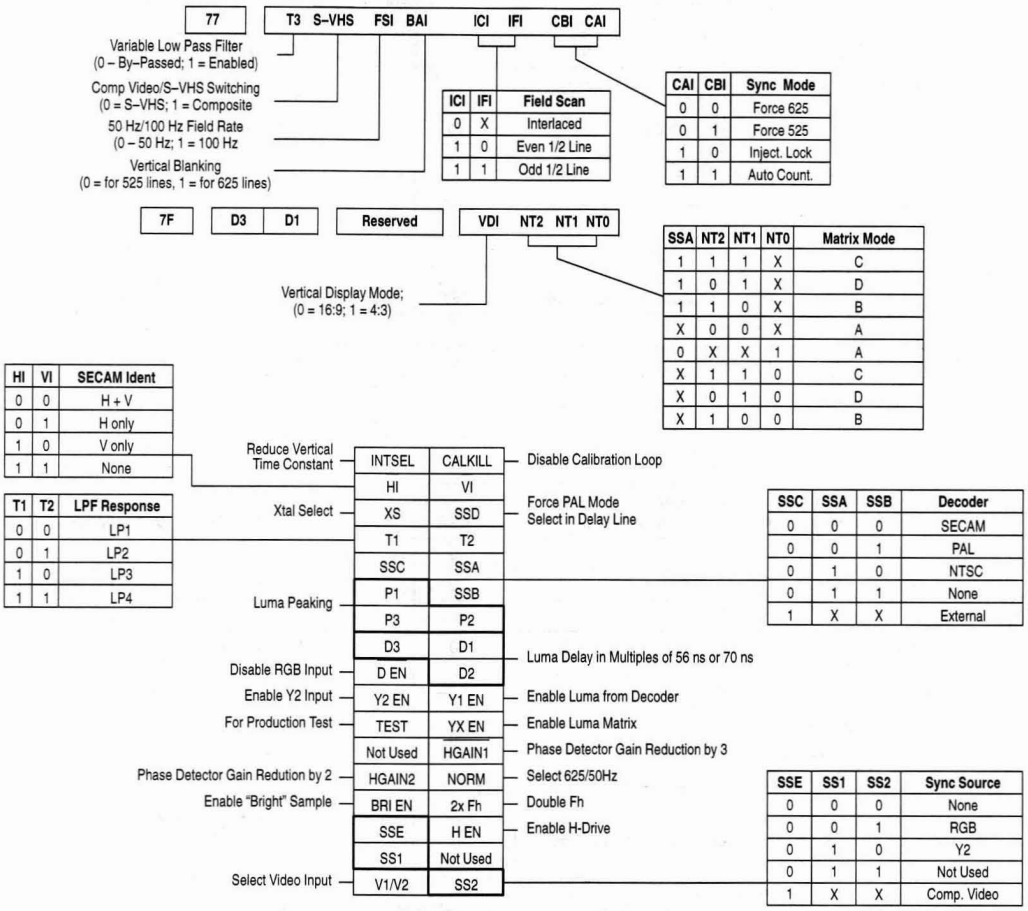
## Table 2b. Register Memory Map


77
T3 S–VHS FSI BAI ICI IFI CBI CAI
Variable Low Pass Filter (0 – By–Passed; 1 = Enabled)
Comp Video/S–VHS Switching (0 = S–VHS; 1 = Composite
50 Hz/100 Hz Field Rate (0 – 50 Hz; 1 = 100 Hz
Vertical Blanking (0 = for 525 lines, 1 = for 625 lines)
ICI IFI Field Scan
0 X Interlaced
1 0 Even 1/2 Line
1 1 Odd 1/2 Line
CAI CBI Sync Mode
0 0 Force 625
0 1 Force 525
1 0 Inject. Lock
1 1 Auto Count.
7F
D3
D1
Reserved
VDI NT2 NT1 NT0
Vertical Display Mode; (0 = 16:9; 1 = 4:3)
SSA NT2 NT1 NT0 Matrix Mode
1 1 1 X C
1 0 1 X D
1 1 0 X B
X 0 0 X A
0 X X 1 A
X 1 1 0 C
X 0 1 0 D
X 1 0 0 B
HI VI SECAM Ident
0 0 H + V
0 1 H only
1 0 V only
1 1 None
T1 T2 LPF Response
0 0 LP1
0 1 LP2
1 0 LP3
1 1 LP4
Reduce Vertical Time Constant
Xtal Select
Luma Peaking
Disable RGB Input
Enable Y2 Input
For Production Test
Phase Detector Gain Redution by 2
Enable "Bright" Sample
Select Video Input
INTSEL CALKILL
HI VI
XS SSD
T1 T2
SSC SSA
P1 SSB
P3 P2
D3 D1
D EN D2
Y2 EN Y1 EN
TEST YX EN
Not Used HGAIN1
HGAIN2 NORM
BRI EN 2x Fh
SSE H EN
SS1 Not Used
V1/V2 SS2
Disable Calibration Loop
Force PAL Mode Select in Delay Line
Luma Delay in Multiples of 56 ns or 70 ns
Enable Luma from Decoder
Enable Luma Matrix
Phase Detector Gain Reduction by 3
Select 625/50Hz
Double Fh
Enable H-Drive
SSC SSA SSB Decoder
0 0 0 SECAM
0 0 1 PAL
0 1 0 NTSC
0 1 1 None
1 X X External
SSE SS1 SS2 Sync Source
0 0 0 None
0 0 1 RGB
0 1 0 Y2
0 1 1 Not Used
1 X X Comp. Video

**NOTES:** SECAM decoding is selectable in the MC44002 only. $\overline{HI}$ and VI must be set to 1,1 in non–SECAM applications.

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**Table 3. Control Bit Truth Tables**

| CAI | CBI | Sync Mode |
|---|---|---|
| 0 | 0 | Force 625 |
| 0 | 1 | Force 525 |
| 1 | 0 | Injection Lock |
| 1 | 1 | Auto Countdown |

| ICI | IFI | Field Scan |
|---|---|---|
| 0 | X | Interlaced |
| 1 | 0 | Even Up 1/2 Line |
| 1 | 1 | Odd Up 1/2 Line |
| | | |

| $\overline{HI}$ | $\overline{VI}$ | SECAM Ident |
|---|---|---|
| 0 | 0 | H + V |
| 0 | 1 | H only |
| 1 | 0 | V only |
| 1 | 1 | None |

| T1 | T2 | LPF Response |
|---|---|---|
| 0 | 0 | LP1 |
| 0 | 1 | LP2 |
| 1 | 0 | LP3 |
| 1 | 1 | LP4 |

| SSC | SSA | SSB | Color Diff. Source |
|---|---|---|---|
| 0 | 0 | 0 | SECAM |
| 0 | 0 | 1 | PAL |
| 0 | 1 | 0 | NTSC |
| 0 | 1 | 1 | None |
| 1 | X | X | External |

| SSE | SS1 | SS2 | Sync Source |
|---|---|---|---|
| 0 | 0 | 0 | None |
| 0 | 0 | 1 | RGB |
| 0 | 1 | 0 | Y2 |
| 0 | 1 | 1 | Not Used |
| 1 | X | X | Comp. Video |

| P2 | P1 | P3 | Luma Peak (dB) @ 3.0 MHz * |
|---|---|---|---|
| 0 | 0 | 0 | 8.5 |
| 0 | 0 | 1 | 8.0 |
| 0 | 1 | 0 | 7.2 |
| 0 | 1 | 1 | 6.3 |
| 1 | 0 | 0 | 5.4 |
| 1 | 0 | 1 | 3.8 |
| 1 | 1 | 0 | 2.3 |
| 1 | 1 | 1 | 0.0 |

* Value shown for 17.7 MHz crystal.
Peak Frequency is ≈ 2.2 MHz when using 14.3 MHz crystal.

| SSA | NT2 | NT1 | NT0 | Matrix Mode |
|---|---|---|---|---|
| 0 | 0 | 0 | X | A |
| 0 | 0 | 1 | 0 | D |
| 0 | 0 | 1 | 1 | A |
| 0 | 1 | 0 | 0 | B |
| 0 | 1 | 0 | 1 | A |
| 0 | 1 | 1 | 0 | C |
| 0 | 1 | 1 | 1 | A |
| 1 | 0 | 0 | X | A |
| 1 | 0 | 1 | X | D |
| 1 | 1 | 0 | X | B |
| 1 | 1 | 1 | X | C |

| $\overline{HGAIN1}$ | HGAIN2 | H–Phase Detector Gain |
|---|---|---|
| 0 | 0 | Divide by 3 (Sync Window Enabled) |
| 0 | 1 | Divide by 6 (Sync Window Enabled) |
| 1 | 0 | High (Sync Window Disabled) |
| 1 | 1 | Divide by 2 (Sync Window Disabled) |

| D1 | D2 | D3 | PAL (T3 = 1) | NTSC (T3 = 1) | SECAM (T3 = 0) | S–VHS (T3 = 0) |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 780 ns | 940 ns | 1050 ns | N/A |
| 0 | 0 | 1 | 836 ns | 1010 ns | 1106 ns | N/A |
| 0 | 1 | 0 | 892 ns | 1080 ns | 1162 ns | N/A |
| 0 | 1 | 1 | 948 ns | 1150 ns | 1218 ns | N/A |
| 1 | 0 | 0 | 1004 ns | 1220 ns | 1274 ns | N/A |
| 1 | 0 | 1 | 1060 ns | 1290 ns | 1330 ns | N/A |
| 1 | 1 | 0 | N/A | N/A | N/A | 480 ns |
| 1 | 1 | 1 | N/A | N/A | N/A | 480 ns |

**SSE, SS1, SS2** – These 3 bits select the signal input from which the timebase synchronization is taken. The composite video input has a high quality sync separator which has been designed to cope with noise and interference on the video; the RGB and Y2 inputs have simple single sync separators which may also be used for synchronization.

**T1, T2** – The bits are used to modify the response of the variable Low Pass Filter placed at the composite video inputs (for PAL/NTSC signals) in order to compensate for IF filtering and the Q of external sound traps.

**P1, P2, P3** – These 3 bits are used to adjust the Luma peaking value. The amount of peaking indicated is with respect to the gain at the minimum peaking value (P1, P2, P3 = 111).

**D1, D2, D3** – These 3 bits are used to adjust the Luma delay. The indicated delay is that from the video inputs (Pins 2 and 40) to the Y1 output. The amount of delay depends on the composite video standard used if S–VHS is selected.

**NT0, NT1, NT2** – These 3 bits are used in conjunction with SSA for the selection of the matrix coefficients mode.

**$\overline{\text{HGAIN1}}$, HGAIN2** – These 2 bits are used to set the gain of the horizontal phase detector. The high gain position is used to acquire lock and for operation with a VCR. Setting $\overline{\text{HGAIN1}}$ to 0 also enables a horizontal sync window. The low gain position is used for off–the–air signals.

The remaining control bits are used singularly and are listed as follows:

**T3** – When high, this bit enables the variable Low Pass Filter at the video inputs. For optimum performance, T3 must be set to 0 in S–VHS and SECAM modes, and to 1 in PAL and NTSC. The filter response is set with bits T1, T2.

**S-VHS** – Set to 1 for normal composite video input to Pin 2 or 40. In this mode, the luma–chroma separator is active. Set to 0 for S–VHS (Y/C) operation at those pins. In this mode, luma is to be applied to the selected video input (with bit V1/V2), and chroma is to be applied to the other input. The luma–chroma separator is bypassed.

**FSI** – Selects either 50 Hz or 100 Hz field rate. When bit is low, 50 Hz operation is selected. No usable with NTSC.

**BAI** – This bit selects the number of blanked lines for either 525 or 625 line standards.

**INTSEL** – The vertical sync separator operates by starting a counter counting up at the beginning of each sync pulse, a field pulse being recognized only if the counter counts up to a sufficiently high value. The control bit INTSEL is used in taking the decision as to when a vertical sync pulse has been detected. When low, the pulse is detected after 36 µs; when high after 68 µs. This may find application with anti-copy techniques used with some VCRs, which rely on a modified or corrupted field sync to allow a TV with a short time constant to display a stable picture. However, a VCR having a longer time constant will be unable to lock to the vertical.

**CALKILL** – Enables or disables the horizontal calibration loop. The loop is normally enabled only during startup for some seconds and when there is no signal present. The loop may be disabled so long as the horizontal timebase is locked to an incoming signal.

**XS** – Is used to change between the two external crystal positions (Pins 32 and 33).

**SSD** – Forces system select to PAL level. Can be used to override SECAM mode in the delay line. When low, SECAM mode is enabled (MC44002 only).

**VDI** – Either 4:3 or 16:9 display mode can be chosen using this bit. When low, the 16:9 mode is enabled.

**$\overline{\text{D EN}}$** – Enables or disables the RGB Fast Commutation switch for the RGB inputs. When low, RGB inputs are enabled.

**Y1 EN** – Switches Y1 through to the color difference stage.

**Y2 EN** – Switches Y2 through to the color difference stage.

**$\overline{\text{Test}}$** – When bit is low, enables continuous sampling by the RGB output control loops throughout the entire field period. Used only for testing the IC.

**YX EN** – Enables the luma matrix allowing saturation control in the color difference stage.

**Norm** – Alters the division ratio for the reference frequency used by the horizontal calibration loop. Always used when changing between 14.3 MHz and 17.7 MHz crystals.

**BRI EN** – Used to switch on or off the "bright" sampling pulses used by the RGB output loops. This feature was originally introduced to prevent any backscatter from these three bright lines in the field interval from getting into the picture. Must be enabled when adjusting intensity Contrast or Red, Green and Blue.

**2x Fh** – Line drive output is either standard 15.625 kHz (15.750 kHz) or at double this rate.

**H EN** – Control bit enables horizontal drive pulse. This is normally done automatically after the values stored in the MCU nonvolatile memory have been read into the MC44002/7 memory.

**V1/V2** – To select between Video Inputs 1 and 2.

**Table 4. Control Bit Functions**

| Bits | Bit Low | Bit High |
|---|---|---|
| T3 | Variable Input LPF By–Passed | Variable Input LPF Enabled |
| $\overline{\text{S–VHS}}$ | S–VHS Mode Enabled | Composite Video Mode Enabled |
| FSI | 50 Hz Field Rate Selected | 100 Hz Field Rate Selected |
| BAI | Vertical Blanking for 525 Lines | Vertical Blanking for 625 Lines |
| INTSEL | Short Vertical Time–Constant | Long Vertical Time–Constant |
| CALKILL | H Calibration Loop Enabled | H Calibration Loop Disabled |
| XS | 17.7 MHz Crystal (Pin 33) Selected | 14.3 MHz Crystal (Pin 32) Selected |
| SSD | System Select Active | System Select Forced to PAL |
| $\overline{\text{D EN}}$ | RGB Inputs Enabled | RGB Inputs Disabled |
| Y2 EN | External Luma Input Switched "Off" | External Luma Input Switched "On" |
| Y1 EN | Luma from Filters Switched "Off" | Luma from Filters Switched "On" |
| $\overline{\text{TEST}}$ | Video Outputs Sampled Continuously | Video Outputs Sampled Once per Field |
| YX EN | Disable Luma Matrix (RGB Saturation Control) | Enable Luma Matrix (RGB Saturation Control) |
| $\overline{\text{HGAIN1}}$ | H–Phase Detector Gain Division by 3 Enabled | H–Phase Detector Gain Division by 3 Disabled |
| HGAIN2 | H–Phase Detector Gain Division by 2 Disabled | H–Phase Detector Gain Division by 2 Enabled |
| NORM | H–Reference Divider Ratio for 17.7 MHz Crystal | H–Reference Divider Ratio for 14.3 MHz Crystal |
| BRI EN | "Bright" Sample Switched "Off" | "Bright" Sample Switched "On" |
| 2 x fH | H–Drive : 1 x fH | H–Drive : 2 x fH |
| H EN | H–Drive Enabled | H–Drive Disabled |
| VDI | 16:9 Display Mode Enabled | 4:3 Display Mode Enabled |
| V1/V2 | Video Input 2 (Pin 2) Selected | Video Input 1 (Pin 40) Selected |

## FLAGS RETURNED BY THE MC44002/7

When the Address Read/Write bit is high the last two bytes of $I^2C$ data are read by the MCU as status flags; a listing of these may be found in Table 5. The MC44002/7 is designed to be part of a closed-loop system with the MCU; these flags are the feedback mechanism which allow the MCU to interact with the MC44002/7.

A brief description of each of the flags, its significance and possible uses are given below.

**Table 5. Flags Returned**

| Clock # | Flag (Bit High) |
|---|---|
| 10 | Horizontal Flyback Present |
| 11 | Horizontal Drive Enabled |
| 12 | Horizontal Out Of Lock |
| 13 | Excess Average Beam Current |
| 14 | Less Than 576 Lines |
| 15 | Vertical Countdown Engaged |
| 16 | Overload Average Beam Current |
| 17 | Reserved |
| 18 | (Acknowledge) |
| 19 | Grid 2 Voltage Up Request |
| 20 | Grid 2 Voltage Down Request |
| 21 | OK |
| 22 | Fault |
| 23 | ACC Active |
| 24 | PAL Identified |
| 25 | SECAM Identified (MC44002 only) |
| 26 | Excess Peak Beam Current |
| 27 | (Acknowledge) |

**Horizontal Flyback Present** – A sense of the horizontal flyback is taken via a current limiting series resistor from one of the flyback transformer secondaries to Pin 13. This is used for the H-phase shift control, but the presence of the pulse is also flagged to the MCU. Should the flag be missing after the chassis has been started up, then the MCU would have to shut down the set immediately.

**Horizontal Drive Enabled** – Indicates that the horizontal drive pulse output at Pin 15 has been enabled. This occurs after the stored values in the nonvolatile memory have been transferred to the MC44002/7 memory.

**Horizontal Out of Lock** – This flag is high when no valid signal is being received by the MC44002/7. Possible action in this case would be to change the phase detector gain and time constant bits to ensure rapid capture and locking to a new signal.

**Excess Average Beam Current** – This is one of two threshold levels which are determined by an external component network connected to the beam current sensing at Pin 9. This flag indicates an excess of beam current. A typical application of this flag in conjunction with "Overload Average Beam Current" flag is for the software controlled Automatic Beam Current Limiting. When this flag is "on", it is recommended that the software prevent increases to the Contrast setting.

**Less Than 576 Lines** – Output from the line counter in the vertical timebase. If there is a count of less than 576 this is indicative of a 525 line system being received. If the flag is low then a 625 line system is being received. This information can be used as part of an automatic system selection software.

**Vertical Countdown Engaged** – The vertical timebase is based on a countdown system. The timebase starts in Injection Lock mode and when vertical retrace is initiated a 4-bit counter is set to zero. A coincidence detector looks for counts of 625 lines. In Auto mode each coincidence causes the counter to count up. When eight consecutive coincidences are detected, the countdown is engaged. The MSB of the counter is used to set this flag to the processor.

**Overload Average Beam Current** – This is the second threshold level which is set by the external component network on Pin 9. The flag warns of an overload in anode current which should be lowered by reducing the Contrast.

**Grid 2 Voltage Up/Down Requests** – These flags indicate when the RGB output loops are about to go out of the control range necessary for correct gray scale tracking. These 2 flags are used during factory adjustment.

**OK and Fault** – These two flags are included as a check on the communication line between the MCU and MC44002/7. The OK flag is permanently wired high and Fault is permanently wired low. The MCU can use these flags to verify that the data received is valid.

**ACC Active** – This flag is high when there is a sufficient level of burst present in PAL and NTSC modes during the video back porch period. The flag goes low when the level of burst falls below a set threshold or if the signal becomes too noisy. The flag is used to implement a software color killer in PAL and NTSC and is also available for system identification purposes. Since in SECAM there is line carrier present during the gating period, it is quite likely that the ACC will be on, or will flicker on and off in this mode.

*** PAL Identified** – Recognizes the line-by-line swinging phase characteristic of the PAL burst. When this flag is on together with the ACC flag, this is positive identification for a PAL signal.

*** SECAM Identified** – Senses the changing line-by-line reference frequencies (Fo1 and Fo2) present during the back porch period of the SECAM signal. This flag alone provides identification that SECAM is being received (MC44002 only).

**Excess Peak Beam Current** – A voltage threshold is set on the beam current feedback on Pin 20, which is also used for the RGB output loops for current sampling. When the threshold is reached, the flag is set, indicating too high a peak beam current which may be in only a part of the screen. The response of the MCU might be to reduce the contrast of the picture. This flag, together with the Excess Average Beam Current flag, performs the function of beam limiting. The exact way in which this is handled is left to the discretion of the user who will have their own requirements, which may be incorporated by the way in which the software is written.

* These two flags are set in opposition to one another such that they can never both be on at the same time. This has been done to try to prevent misidentification from occurring. Often it is very difficult to distinguish between PAL and SECAM especially when broadcast material has been transcoded, sometimes badly, leaving e.g. large amounts of SECAM carrier in a transcoded PAL signal (also often with noise). With this method the strongest influence will win out making a misidentification much less likely.

## APPENDIX A – SYSTEM IDENTIFICATION TABLE

The table below can be used for color standard selection between the normal PAL (I, BG), SECAM (L, BG) and NTSC (3.58 MHz – M) standards. Detecting the hybrid VCR standard (525 lines with 4.4 MHz chrominance) would entail switching back to the 17.7 MHz crystal in the event of there being no flag present with the 14.3 MHz crystal. The MC44002/7 could also be used for the PAL M and N standards that are used in some parts of South America, but because the subcarrier frequencies differ by some kHz from the normal, crystals with a different center frequency would be required.

**Table 6. System Identification**

| Flags from the MC44002/7 | | | | Crystal (MHz) | Standard Selected By MCU |
|---|---|---|---|---|---|
| <576 Lines | ACC On | PAL | SECAM | | |
| 0 | 0 | 0 | 0 | 17.7 | Kill |
| 0 | 0 | 0 | 1 | 17.7 | SECAM |
| 0 | 0 | 1 | 0 | 17.7 | Kill |
| 0 | 0 | 1 | 1 | 17.7 | $I^2C$ Bus Error |
| 0 | 1 | 0 | 0 | 17.7 | Kill |
| 0 | 1 | 0 | 1 | 17.7 | SECAM |
| 0 | 1 | 1 | 0 | 17.7 | PAL |
| 0 | 1 | 1 | 1 | 17.7 | $I^2C$ Bus Error |
| 1 | 0 | 0 | 0 | 14.3 | NTSC Kill |
| 1 | 0 | 0 | 1 | 14.3 | NTSC Kill |
| 1 | 0 | 1 | 0 | 14.3 | NTSC Kill |
| 1 | 0 | 1 | 1 | 14.3 | $I^2C$ Bus Error |
| 1 | 1 | 0 | 0 | 14.3 | NTSC |
| 1 | 1 | 0 | 1 | 14.3 | NTSC |
| 1 | 1 | 1 | 0 | 14.3 | NTSC |
| 1 | 1 | 1 | 1 | 14.3 | $I^2C$ Bus Error |

## APPENDIX B – I²C BUS AND RGB CONTROL LOOPS WITH MC44002/7

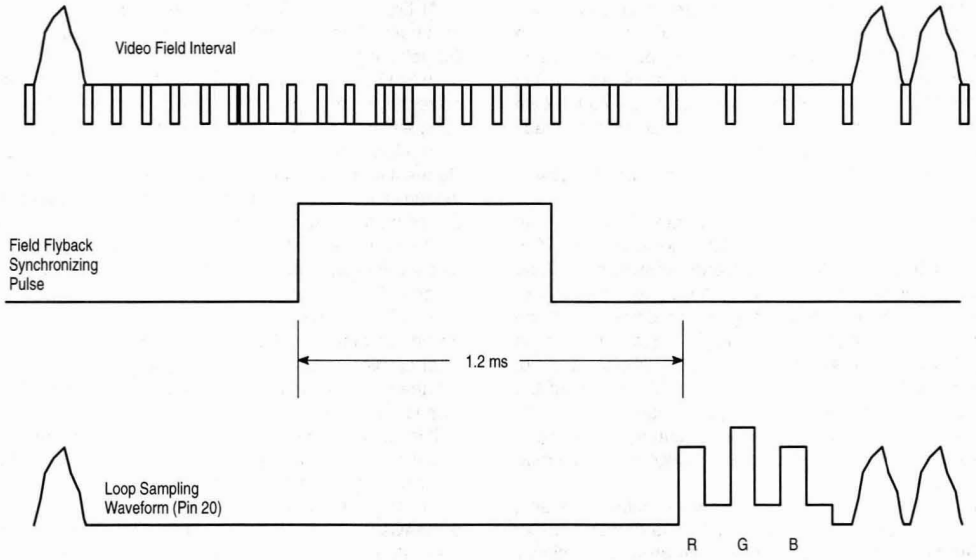
The RGB drive DACs cannot be buffered on account of the chip area that this would take up. This factor has considerable implications on the way that the I²C data is written into the MC44002/7 memory. If the data for Brightness, Contrast, Saturation and Hue are transmitted at just any time, a disturbance will be visible on the screen.

To overcome this difficulty, a method synchronizing the MCU to write data only during the field interval has been developed. This represents something of a limitation, but has to be used only for the 4 user controls.

Another characteristic of the MC44002/7 is that the Contrast control function is carried out within the RGB sampling loops. If data is written into the registers during the time when the RGB loops are taking their samples, then the situation arises where data is being sampled and changed at the same time. Hence, the loops will inevitably go unstable. When this happens, the brightness is seen to vary uncontrollably while the Contrast is changed. The effect has been described as "loop bounce".

The timing diagram below show the exact situation.

From the start of the field flyback pulse to the beginning of the RGB sampling, approximately 1.2 ms is available to write the I²C data. Therefore, with a reasonable safety margin, the write time should be limited to only about 1.0 ms. This should not present any serious difficulty since only the data byte has to be transmitted during this time, and then only for the 4 user controls.

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## APPENDIX C – A SUGGESTED METHOD FOR OUTPUT LOOPS ADJUSTMENT

As described in section 4, the MC44002/7 output loops stage automatically adjust the dc level of the cathode voltage (cut–off) and the gain of the signal at the cathode (white balance). These automatic adjustments replace the conventional manual adjustments. The only adjustment that must be carried out, either by hand or automatically using an "intelligent screwdriver", is for the G2 voltage.

As the G2 voltage is varied, the automatic output loops of the MC44002/7 will adjust the cathode voltage of the dark sample level to always obtain the correct dark cathode current. However, if the G2 voltage is adjusted too high or too low, one or more of the DAC's controlling the dc level will reach the end of their range and the cathode voltage on the channel will not be correctly adjusted. In order to inform the operator or machine adjusting the G2 voltage that the control range has been exceeded, the G2–Up Request or G2–Down Request flags will be set. These flags are set when any one of the dc–DAC's approaches the end of its range. The threshold for setting the flags lies typically between 15 and 20% of the range from the actual end. Therefore, when a flag is set, the output loops can still operate correctly. As the gain of the picture tube varies very little with the G2 voltage, flags are not provided for the gain–DAC's.

In order to fix a procedure for setting the G2 voltage it is necessary to consider several points:

– On a given sample, the output currents from the three channels corresponding to the dark level are all different. The range of each DAC is about 2.4 mA and varies little from one channel to another and from one device to another. For reasons of stability and control range we recommend that the feedback resistor of the high–voltage video amplifier be 39 kΩ. this means that the dark cathode voltage range of each channel is about 94 V (i.e. 39 kΩ x 2.4 mA), but the absolute value of the cathode voltage can vary.

– In a typical application the actual cut–off voltage (i.e. zero cathode current) lies about 10–15 V higher than the dark cathode current (10 μA).

– When the beam–current in the picture tube increases, the G2 voltage tends to decrease. With the output loops of the MC44002/7, the cathode voltage is lowered automatically to compensate, but this effect would normally cause the values in the dc–DAC's to fall, using up their useful control range. as high beam current is associated to high contrast, in the MC44002/7 the dc output current (and therefore the cathode voltage) is reduced directly as the contrast setting is increased. In this way as contrast is increased, leading to higher beam current and lower G2 voltage, the dc–DAC's do not move much, thus saving range.

– A picture tube can have a difference in cut–off voltage between guns of up to about 30 V and it is not generally possible to identify in a particular type and make of tube which gun has the lowest and which gun has the highest cut–off voltage. Also, it is generally recommended by the tube manufacturer to set the cut–off voltage of the highest gun to a certain value which gives optimum focus performance.

– As the picture tube ages, the cathode cut–off voltage falls. It is therefore best to set the G2 voltage when the tube is new to give the highest possible cathode cut–off voltage.

Taking into account the above points, it is recommended that the G2 voltage be set up in the following way:

1) Display a black picture with the brightness control to minimum. (This give minimum beam current and no drop in G2 voltage.)

2) Set he contrast to maximum. (This causes the dc output current to be forced to a lower level and the output loops to compensate by moving towards the top of their range.)

3) Now adjust the G2 voltage so that the G2 Down Request flag is just turned off. (All the dc–DAC's are towards the top of their range and the highest one is just at the level to switch on the flag. Lowering the contrast setting, increasing the beam current or aging of the tube will cause the output loops to reduce the values in the dc–DAC's, but the available range will be a maximum.)

4) With a white picture and contrast set to give the maximum allowable beam current, check that the G2 Up Request flag is still off. (This is just to check that the G2 voltage is not falling too much at high beam current, but this step is not absolutely necessary.)

It is not recommended adjusting the G2 voltage to reach a specific value of cathode cut–off or dark voltage. The reason for this is that tolerances of the picture tube, high voltage video amplifier and the MC44002/7 itself will cause the dc–DACs to be set anywhere in their range and perhaps near the bottom end, leaving no margin for aging and G2 voltage drop.

MOTOROLA

# MC44011

*Advance Information*

## Bus Controlled Multistandard Video Processor

**BUS CONTROLLED MULTISTANDARD VIDEO PROCESSOR**

**SEMICONDUCTOR TECHNICAL DATA**

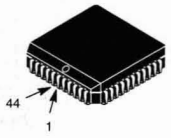
The Motorola MC44011, a member of the MC44000 Chroma 4 family, is designed to provide RGB or YUV outputs from a variety of inputs. The inputs can be composite video (two inputs), S–VHS, RGB, and color difference (R–Y, B–Y). The composite video can be PAL and/or NTSC as the MC44011 is capable of decoding both systems. Additionally, R–Y and B–Y outputs and inputs are provided for use with a delay line where needed. Sync separators are provided at all video inputs.

In addition, the MC44011 provides a sampling clock output for use by a subsequent triple A/D converter system which digitizes the RGB/YUV outputs. The sampling clock (6.0 to 40 MHz) is phase–locked to the horizontal frequency.

Additional outputs include composite sync, vertical sync, field identification, luma, burst gate, and horizontal frequency.

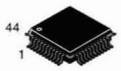
Control of the MC44011, and reading of status flags, is via an $I^2C$ bus.

- Accepts NTSC and PAL Composite Video, S–VHS, RGB, and R–Y, B–Y
- Includes Luma and Chroma Filters, Luma Delay Lines, and Sound Traps
- Digitally Controlled via $I^2C$ Bus
- R–Y, B–Y Inputs for Alternate Signal Source
- Line–Locked Sampling Clock for A/D Converters
- Burst Gate, Composite Sync, Vertical Sync and Field Identification Outputs
- RGB/YUV Outputs can Provide 3.0 Vpp for A/D Inputs
- Overlay Capability
- Single Power Supply: 5.0 V, ±5%, 550 mW (Typical)
- 44 Pin PLCC and QFP Packages




**FN SUFFIX**
PLASTIC PACKAGE
CASE 777
(PLCC)

**FB SUFFIX**
PLASTIC PACKAGE
CASE 824E
(QFP)




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44011FN | $T_A$ = 0° to +70°C | PLCC–44 |
| MC44011FB | | QFP |

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**Representative Block Diagram**

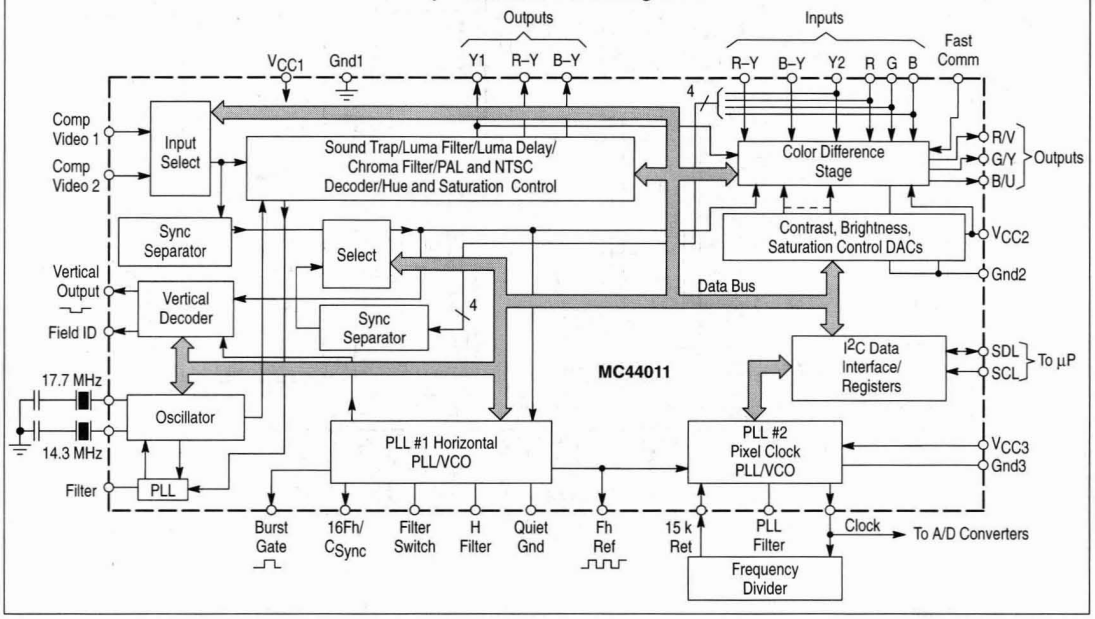
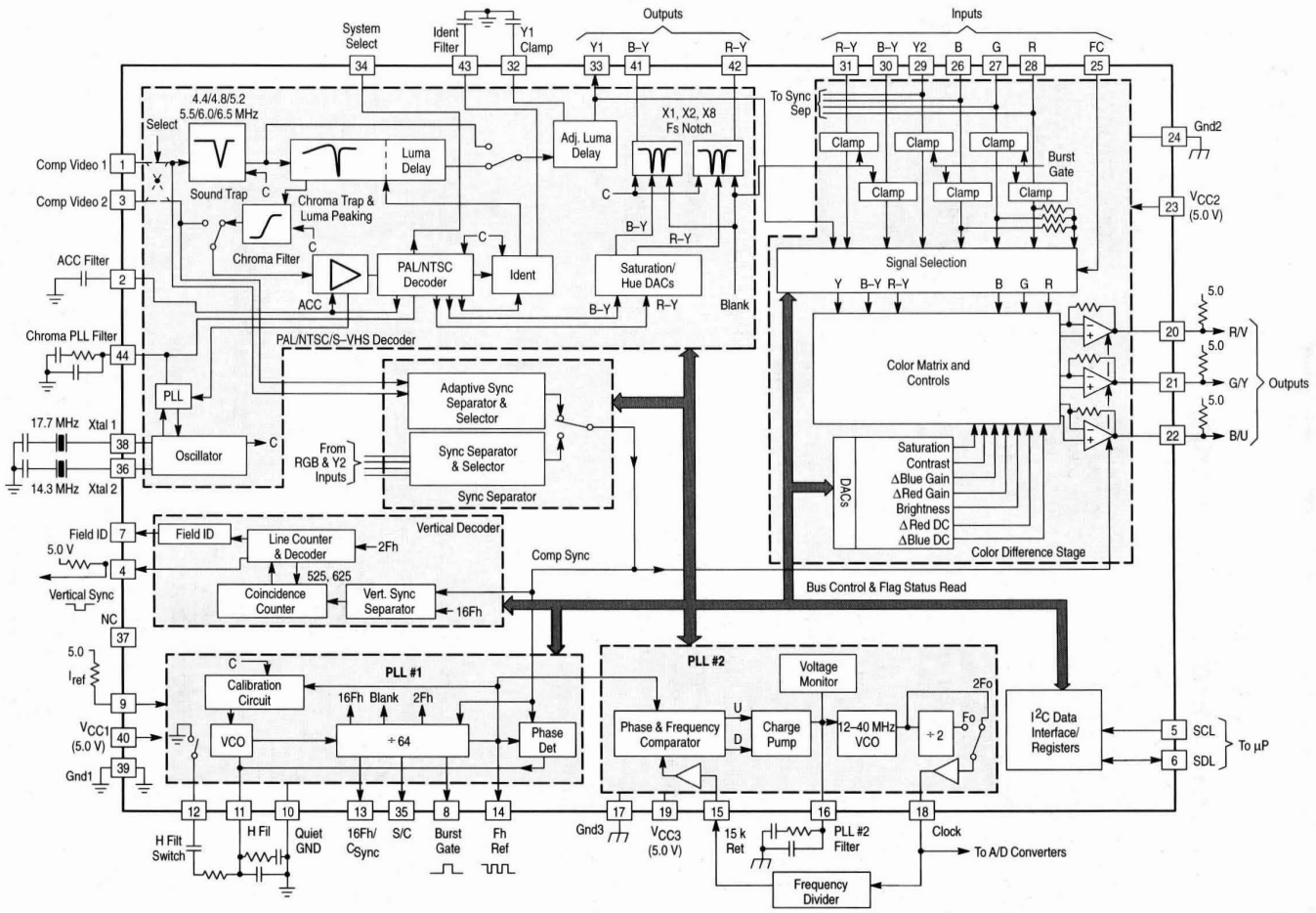


**Figure 1. Representative Block Diagram**



**ELECTRICAL CHARACTERISTICS** (The tested electrical characteristics are based on the conditions shown in Table 1 and 2. Composite Video input signal = 1.0 Vpp, composed of: 0.7 Vpp Black–to–White; 0.3 Vpp Sync–to–Black; 0.3 Vpp Color Burst. $V_{CC1} = V_{CC2} = V_{CC3} = 5.0$ V, $I_{ref} = 32$ µA (Pin 9), unless otherwise noted.)

**Table 1. Control Bit Test Settings**

| Control Bit | Name | Value | Function |
|---|---|---|---|
| $77–7 | S–VHS–Y | 0 | Composite Video input selected. |
| $77–6 | S–VHS–C | 0 | Composite Video input selected. |
| $77–5 | FSI | 0 | 50 Hz Field Rate selected. |
| $77–4 | $\overline{\text{L2 GATE}}$ | 0 | PLL #2 Gating enabled. |
| $77–3 | $\overline{\text{BLCP}}$ | 0 | Clamp Pulse Gating enabled. |
| $77–2 | $\overline{\text{L1 GATE}}$ | 0 | Vertical Gating enabled. |
| $77–1, 0 | CB1, CA1 | 1,1 | Vertical section Auto–Countdown mode |
| $78–7 | 36/68 µs | 0 | Time from beginning of Line 4 to Vertical Sync is 36 µs. |
| $78–6 | CalKill | 0 | Horizontal Calibration Loop enabled. |
| $79–7, 6 | HI, VI | 1,1 | Normal |
| $7A–7 | Xtal | – | 0 = 17.7 MHz crystal selected, 1 = 14.3 MHz crystal selected. |
| $7A–6 | SSD | 0 | Normal |
| $7B–7, 6 | T1, T2 | 1,1 | Sound Trap Notch filter set to 5.5 MHz (with 17.7 MHz crystal). |
| $7C–7 | SSC | 0 | Permits PAL and NTSC selection. |
| $7C–6, $7D–6 | SSA, SSB | – | 0, 1 = PAL decoding, 1,0 = NTSC decoding |
| $7D–7, $7E–7, 6 | P1, P3, P2 | 1, 1, 1 | Sets Luma Peaking at 0 dB. |
| $7F–7, 6, $80–6 | D3, D1, D2 | 0, 0, 0 | Set Luma Delay to minimum |
| $80–7 | $\overline{\text{RGB EN}}$ | 0 | Fast Commutate input can enable RGB inputs. |
| $81–7 | Y2 EN | 0 | Y2 input (Pin 29) deselected |
| $81–6 | Y1 EN | 1 | Y1 luma path from PAL/NTSC decoder selected. |
| $82–7 | YUV EN | 0 | RGB output mode selected |
| $82–6 | YX EN | 0 | Disable luma matrix from RGB inputs. |
| $83–7 | L2 Gain | 0 | Set PLL #2 Phase/Frequency detector gain high. |
| $83–6 | L1 Gain | 1 | Set PLL #1 Phase Detector gain high. |
| $84–7 | H Switch | 0 | Set Horizontal Phase Detector filter switch open. |
| $84–6 | 525/625 | – | 0 = 625 lines (PAL), 1 = 525 lines (NTSC) |
| $85–7 | $F_{osc} \div 2$ | 0 | Select direct VCO output from PLL #2. |
| $85–6 | $C_{Sync}$ | 0 | 16 Fh output selected at Pin 13. |
| $86–7 | $V_{in}$ Sync | 1 | Composite Video inputs (Pin 1 or 3) Sync Source selected. |
| $86–6 | H EN | 0 | Enabled Horizontal Timebase. |
| $87–7 | Y2 Sync | 0 | Y2 sync source not selected. |
| $88–7 | V2/V1 | 1 | Select Video 1 input (Pin 1). |
| $88–6 | RGB Sync | 0 | RGB inputs Sync Source not selected. |

**Table 2. DAC Test Settings**

| DAC | Value | Function | DAC | Value | Function |
|---|---|---|---|---|---|
| $78 | 32 | R–Y/B–Y Gain | $82 | 32 | Red Contrast Trim |
| $79 | 32 | Sub Carrier Phase | $83 | 32 | Blue Brightness Trim |
| $7D | 00 | Blue Output DC Bias | $84 | 32 | Main Brightness |
| $7E | 00 | Red Output DC Bias | $85 | 32 | Red Brightness Trim |
| $7F | 63 | Pixel Clock VCO Gain | $86 | 32 | Saturation (Color Diff.) |
| $80 | 32 | Blue Contrast Trim | $87 | 16 | Saturation (Decoder) |
| $81 | 32 | Main Contrast | $88 | 32 | Hue |

**NOTE:** Currents out of a pin are designated –, and those into a pin are designated +.

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC1}$<br>$V_{CC2}$<br>$V_{CC3}$ | –0.5 to +6.0<br>–0.5 to +6.0<br>–0.5 to +6.0 | Vdc |
| Power Supply Difference (Between any two $V_{CC}$ pins) | – | ±0.5 | Vdc |
| Input Voltage: Video 1, 2, SCL, SDL<br>15 kHz Return<br>R–Y, B–Y, Y2, RGB, FC | $V_{in}$ | –0.5, $V_{CC1}$ +0.5<br>–0.5, $V_{CC3}$ +0.5<br>–0.5, $V_{CC2}$ +0.5 | Vdc |
| Junction Temperature (Storage and Operating) | $T_J$ | –65 to +150 | °C |

**NOTES:** 1. Devices should not be operated at these limits. The "Recommended Operating Conditions" table provides for actual device operation.

2. ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Power Supply Voltage | $V_{CC1, 2, 3}$ | 4.75 | 5.0 | 5.25 | Vdc |
| Power Supply Difference (Between any two $V_{CC}$ pins) | $\Delta V_{CC}$ | –0.5 | 0 | 0.5 | Vdc |
| Input Voltage: Video 1, 2 (Sync–White) | $V_{in}$ | 0.7 | 1.0 | 1.4 | Vpp |
| Chroma (S–VHS Mode) | | – | – | 1.2 | |
| Y2 | | 0.7 | 1.0 | 1.4 | |
| RGB | | 0.5 | 0.7 | 1.0 | |
| R–Y, B–Y (Pins 30, 31) | | 0 | – | 1.8 | |
| 15 kHz Return | | 0 | – | $V_{CC3}$ | Vdc |
| SCL, SDL | | 0 | – | $V_{CC1}$ | |
| FC | | 0 | – | $V_{CC2}$ | |
| Burst Signal | | 30 | 280 | 560 | mVpp |
| Sync Amplitude | | 60 | 300 | $V_{CC1}$ | mVpp |
| Output Load Impedance to Ground: RGB (Pull–Up = 390 Ω) | $RL_{RGB}$ | 1.0 | – | ∞ | kΩ |
| B–Y, R–Y | $RL_{CD}$ | 10 | – | ∞ | |
| Y1 | $RL_{Y1}$ | 1.0 | – | ∞ | |
| Pull–Up Resistance at Vertical Sync (Pin 4) | $R_{VS}$ | 1.0 | 10 | – | kΩ |
| Source Impedance: Video 1, 2 | – | 0 | – | 1.0 | kΩ |
| Pins 26 to 31 | | 0 | – | 1.0 | |
| Pixel Clock Frequency (Pin 18, see PLL #2 Electrical Characteristic) | $f_{px}$ | – | 2.0 to 45 | – | MHz |
| 15 kHz Return Pulse Width (Low Time) | $PW_{15k}$ | 0.2 | – | 45 | µs |
| $I^2C$ Clock Frequency | $f_{I^2C}$ | – | – | 100 | kHz |
| Reference Current (Pin 9) | $I_{ref}$ | – | 32 | – | µA |
| Operating Ambient Temperature | $T_A$ | 0 | – | 70 | °C |

**NOTE:** All limits are not necessarily functional concurrently.

## ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = $V_{CC3}$ = 5.0 V, unless otherwise noted.)

| Characteristics | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER SUPPLIES** | | | | | |
| Power Supply Current ($V_{CC}$ = 5.0 V) | Pin 40 | 75 | 95 | 115 | mA |
| | Pin 23 | 6.0 | 9.0 | 12 | |
| | Pin 19 | 3.5 | 6.0 | 8.0 | |
| | Total | 85 | 110 | 135 | |

**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = $V_{CC3}$ = 5.0 V, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **PAL/NTSC/S–VHS DECODER** | | | | |
| Video 1, 2 Inputs | | | | |
| Crosstalk Rejection, f = 1.0 MHz (Measured at Y1 output, Luma Peaking = 0 dB, $77–7 = 1) | 20 | 40 | – | dB |
| DC Level: @ Selected Input | – | 2.8 | – | Vdc |
| @ Unselected Input | – | 0.7 | – | |
| Clamp Current | –30 | –20 | –10 | µA |
| Sound Trap Rejection (See Figures 14 to 23) | | | | |
| With 17.7 MHz Crystal: @ 6.5 MHz (T1, T2 = 00) | 15 | 30 | – | dB |
| @ 6.0 MHz (T1, T2 = 10) | 15 | 30 | – | |
| @ 5.5 MHz (T1, T2 = 11) | 10 | 43 | – | |
| @ 5.74 MHz (T1, T2 = 01) | 15 | 26 | – | |
| With 14.3 MHz Crystal: @ 4.44 MHz (T1, T2 = 11) | – | 35 | – | |
| R–Y, B–Y Outputs (Pins 41, 42) | | | | |
| Output Amplitude (with 100% Saturated Color Bars) | | | | |
| Saturation (DAC 87) = 00 | – | <1.0 | – | mVpp |
| Saturation (DAC 87) = 16 | – | 1.6 | – | Vpp |
| Saturation (DAC 87) = 63 | 1.8 | 3.0 | – | |
| DC Level During Blanking | – | 2.4 | – | Vdc |
| Hue Control – Minimum Phase (DAC 88 = 00) | – | –30 | – | Deg |
| – Maximum Phase (DAC 88 = 63) | – | 30 | – | |
| Nominal Saturation (with respect to Y1 Output, Note 1) | – | 100 | – | % |
| R–Y/B–Y Ratio: Balance (DAC 78) = 63 | 1.35 | 1.69 | 2.06 | V/V |
| Balance (DAC 78) = 32 | 0.98 | 1.27 | 1.58 | |
| Balance (DAC 78) = 00 | 0.60 | 0.77 | 0.96 | |
| Output Amplitude Variation as Burst is varied from 80 mVpp to 600 mVpp | – | 3.0 | – | dB |
| Color Kill Attenuation ($7C–7, 6 and $7D–6 = 011) | – | 40 | – | dB |
| Crosstalk with respect to Y1 Output (@ 1.0 MHz) | –27 | –20 | – | |
| Chroma Subcarrier Residual | | | | |
| (Measured at Y1 Output, with 17.7 MHz Crystal) | | | | |
| f = Subcarrier | – | 25 | 60 | mVpp |
| 2nd Harmonic Residual | – | 4.0 | 12 | |
| 4th Harmonic Residual | – | 12 | 30 | |
| (Measured at R–Y, B–Y Outputs, with 17.7 or 14.3 MHz Crystal) | | | | |
| f = Subcarrier | – | 5.0 | 20 | |
| 2nd Harmonic Residual | – | 5.0 | 20 | |
| 4th Harmonic Residual | – | 15 | 50 | |
| Y1 Luma Output (Pin 33) | | | | |
| Clamp Level | 0.4 | 1.1 | 1.8 | Vdc |
| Output Impedance | – | 300 | – | Ω |
| Composite Video Mode ($77–6, 7 = 00) | | | | |
| Output Level versus Input Level | | | | |
| Delay = 000, Peaking = 111, f = 100 kHz | 1.0 | 1.1 | 1.2 | V/V |
| Delay = Min–to–Max, Peaking = Min–to–Max | – | 1.1 | – | |
| –3.0 dB Bandwidth (17.7 MHz Crystal, PAL Decoding selected, Sound trap at 6.5 MHz, Peaking off) | – | 2.8 | – | MHz |
| Peaking Range ($7D–7, $7E–6/7 = 000 to 111, @ 3.0 MHz, with 17.7 MHz Crystal, Sound trap at 6.5 MHz) | 5.0 | 8.0 | 10 | dB |
| Overshoot with Minimum Peaking | – | 0 | – | % |
| Differential Non–linearity (Measured with Staircase) | – | 2.0 | – | % |
| Delay (Pin 1 or 3 to 33) | | | | |
| With 14.3 MHz Crystal: Minimum | – | 690 | – | ns |
| Maximum | – | 1040 | – | |
| With 17.7 MHz Crystal: Minimum | – | 594 | – | |
| Maximum | – | 876 | – | |

**NOTE:** 1. This spec indicates a correct output amplitude at Pins 41 and 42, with respect to Y1 output. For standard color bar inputs, the output amplitude is between 1.5 and 1.7 Vpp, with the settings in Tables 1 and 2.

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**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = $V_{CC3}$ = 5.0 V, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **PAL/NTSC/S–VHS DECODER** | | | | |
| S–VHS Mode ($77–6, 7 = 11) | | | | |
| Output Level versus Input Level (Delay = Min–to–Max) | 1.0 | 1.1 | 1.2 | V/V |
| –3.0 dB Bandwidth (17.7 MHz crystal, PAL Decoding selected, Sound trap at 6.5 MHz) | – | 4.5 | – | MHz |
| Y/C Crosstalk Rejection | 20 | 40 | – | dB |
| Delay (Luma input to Pin 33) | | | | |
| 14.3 MHz Crystal: Minimum | – | 395 | – | ns |
| Maximum | – | 745 | – | |
| 17.7 MHz Crystal: Minimum | – | 350 | – | |
| Maximum | – | 632 | – | |
| Crystal Oscillator | | | | |
| PLL Pull–in range with respect to Subcarrier Frequency | | | | |
| (Burst Level ≥ 30 mVpp): with 17.7 MHz Crystal | – | ±350 | – | Hz |
| with 14.3 MHz Crystal | – | ±300 | – | |
| $4f_{sc}$ Filter (Pin 44) DC Voltage | | | | |
| @ 14.3 MHz | – | 2.4 | – | Vdc |
| @ 17.7 MHz | – | 3.5 | – | |
| No Burst present | – | 1.3 | – | |
| DC Voltages | | | | Vdc |
| System Select (Pin 34) | | | | |
| NTSC Mode (SSA = 1, SSB = 0, SSC = 0, SSD = 0) | 1.5 | 1.75 | 2.0 | |
| PAL Mode (SSA = 0, SSB = 1, SSC = 0, SSD = 0) | 0 | 0.075 | 0.4 | |
| Color Kill Mode (SSA = 1, SSB = 1, SSC = 0, SSD = 0) | – | 0.075 | – | |
| External Mode (SSA = X, SSB = X, SSC = 1, SSD = 0) | 3.7 | 4.0 | 4.3 | |
| Ident Filter (Pin 43) | | | | |
| NTSC Mode | – | 1.6 | – | |
| PAL Mode | 1.2 | 1.5 | 1.8 | |
| No Burst present | – | 0.2 | – | |
| ACC Filter (Pin 2) | | | | |
| No Burst present | – | 0.25 | – | |
| Threshold for ACC Flag on | 0.8 | 1.2 | 1.6 | |
| Burst = 50 mVpp | – | 1.4 | – | |
| Burst = 280 mVpp | – | 1.7 | – | |
| System Select Output Impedance | – | 40 | 100 | kΩ |
| **COLOR DIFFERENCE SECTION** | | | | |
| RGB/YUV Outputs | | | | |
| Output Swing, Black–to–White (DAC $81 = 63) | 2.0 | 3.0 | – | Vpp |
| THD (RGB Inputs to RGB Outputs @ 1.0 MHz, 0.7 Vpp) | – | 0.5 | 2.0 | % |
| –3.0 dB Bandwidth | – | 6.0 | – | MHz |
| Clamp Level | | | | |
| RGB Outputs ($7D, 7E = 00) | – | 1.4 | – | Vdc |
| UV Outputs ($7D, 7E = 32) | – | 2.3 | – | |
| Red, Blue Clamp Level Change (DACs $7D, 7E varied from 00 to 63) | 0.85 | 1.8 | 2.4 | |
| Crosstalk Rejection | | | | |
| Among RGB Outputs @ 1.0 MHz | 20 | 40 | – | dB |
| Y1 to Y2 | 20 | 40 | – | |
| From RGB Outputs to Y1 or Y2 | 20 | 40 | – | |
| Input Black Clamp Voltage at Y2, B–Y, R–Y, and RGB | 2.4 | 3.0 | 3.6 | Vdc |
| Fast Commutate Input (Pin 25) | | | | |
| Switching Threshold Voltage | – | 0.5 | – | Vdc |
| Input Current @ $V_{in}$ = 0 V | – | –7.5 | – | μA |
| Input Current @ $V_{in}$ = 5.0 V | – | 0 | – | |
| Timing: Input Low–to–High (RGB Enable) | – | 50 | – | ns |
| Input High–to–Low (RGB Disable) | – | 90 | – | |

**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = $V_{CC3}$ = 5.0 V, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **COLOR DIFFERENCE SECTION** | | | | |
| Contrast (Gain) | | | | V/V |
| Y1 to RGB (DAC $81 = 32, DAC $86 = 00) | 1.9 | 2.4 | 3.0 | |
| Y2 to RGB (DAC $81 = 32, DAC $86 = 00) | 1.8 | 2.3 | 2.8 | |
| Green In (Pin 27) to Green Out (Pin 21) with YX Enabled ($82–6 = 1, DAC $81 and DAC $86 = 32) | 1.8 | 2.3 | 2.4 | |
| Red–to–Green and Blue–to–Green Gain Ratio | 0.8 | 1.0 | 1.2 | |
| RGB Input to RGB Output with YX Not Enabled ($82–6 = 0, DAC $81 and DAC $86 = 32) | 2.0 | 2.6 | 3.2 | |
| Ratio (DAC $81 = 00 versus 32) | – | 0.2 | 0.4 | |
| Ratio (DAC $81 = 63 versus 32) | 1.5 | 2.0 | 2.5 | |
| Red and Blue Trim Control (DACs $80, 82 varied from 00 to 63) | ±5.0 | ±30 | ±60 | % |
| Saturation (Average of R, G, B saturation levels with respect to Luma) | | | | |
| Inputs at Pins 29 to 31 (DAC $86 = 32) | 50 | 90 | 130 | % |
| Ratio (DAC $86 = 00 versus 32) | – | – | 5 | |
| Ratio (DAC $86 = 63 versus 32) | 150 | 170 | 190 | |
| Inputs at Pins 26 to 28 (DAC $86 = 32, $82–6 = 1) | 70 | 125 | 180 | |
| Brightness | | | | |
| Black Level Range (Brightness = 00 to 63 with respect to Brightness setting of 32) | ±0.3 | ±0.5 | ±0.7 | Vdc |
| Red and Blue Trim Control (DACs $83, 85 varied from 00 to 63) | ±0.05 | ±0.3 | ±0.6 | |
| Color Coefficients | | | | |
| G–Y Matrix Coefficient versus B–Y | –0.21 | –0.19 | –0.17 | |
| G–Y Matrix Coefficient versus R–Y | –0.56 | –0.51 | –0.46 | |
| YX Matrix (Inputs at Pins 26 to 28, $82–6 = 1): | | | | |
| Y versus R | 0.28 | 0.30 | 0.32 | |
| Y versus G | 0.57 | 0.59 | 0.61 | |
| Y versus B | 0.09 | 0.11 | 0.13 | |
| **HORIZONTAL TIME BASE SECTION (PLL #1)** | | | | |
| Free–Running Period (Calibration mode in effect, Bit $86–6 = 1) | | | | |
| 17.7 MHz Crystal selected ($84–6 = 0) | 62.5 | 64.0 | 65.5 | µs |
| 14.3 MHz Crystal selected ($84–6 = 1) | 62.5 | 63.5 | 65.5 | |
| VCO minimum period (Pin 11 Voltage at 1.2 V) | 56 | 59.5 | 62 | µs |
| VCO maximum period (Pin 11 Voltage at 2.8 V) | 66 | 69.5 | 72 | |
| VCO Control Gain factor | 5.0 | 8.5 | 12 | µs/V |
| Phase Detector Current | | | | |
| High Gain ($83–6 = 1) | 15 | 50 | 85 | µA |
| Low Gain–to–High Gain Current Ratio | 0.32 | 0.38 | 0.44 | µA/µA |
| Noise Gate Width ($77–2 = 0, Low Gain, see Figure 26) | – | 16 | – | µs |
| Horizontal Filter Switch (Pin 12) | | | | |
| Saturation Voltage ($I_{12}$ = 20 µA) | – | 10 | 100 | mV |
| Dynamic Impendance ($84–7 = 1) | – | <5.0 | – | kΩ |
| Parallel Resistance ($84–7 = 0) | 0.6 | 1.0 | – | MΩ |
| Pins 8, 13, 14 Output Level | | | | |
| High ($I_O$ = –40 µA) | 2.4 | 4.5 | – | Vdc |
| Low ($I_O$ = 800 µA) | – | 0.1 | 0.8 | |
| Burst Gate (Pin 8) Timing (See Figures 25, 27) | | | | µs |
| Rising edge from Sync leading edge (Pins 1, 3) | 4.4 | 5.6 | 6.8 | |
| Rising edge from Sync center (Pins 26 to 29) | – | 2.5 | – | |
| Pulse Width | 3.0 | 3.5 | 4.0 | |
| 16Fh Output (Pin 13) Timing (Bit $85–6 = 0) (See Figures 25, 27) | | | | |
| Rising edge from Fh rising edge | – | 1.3 | – | µs |
| Duty Cycle | – | 50 | – | % |
| Composite Sync Output (Pin 13) Timing (Bit $85–6 = 1) | | | | µs |
| Input Sync center to Output Sync center (Pins 1, 3) | – | 0.95 | – | |
| Input Sync center to Output Sync center (Pins 26 to 29) | – | 0.4 | – | |

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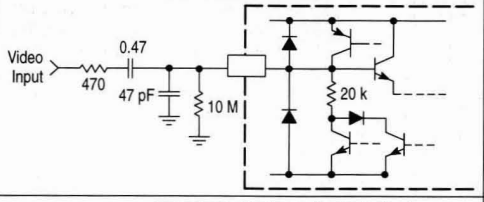
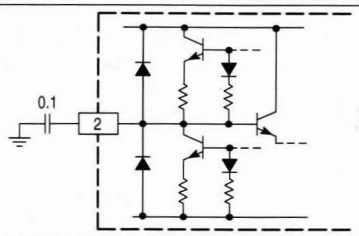
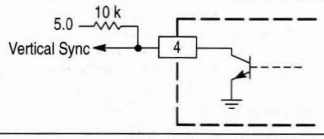
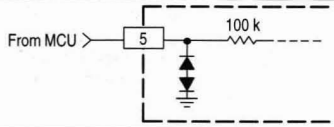
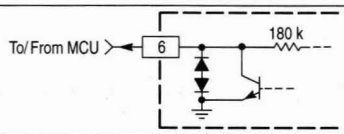
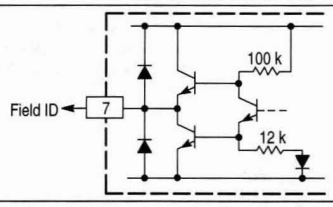
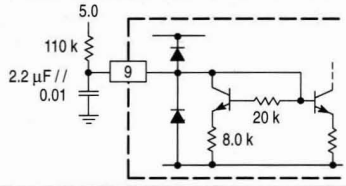
**ELECTRICAL CHARACTERISTICS (continued)** ($T_A$ = 25°C, $V_{CC1}$ = $V_{CC2}$ = $V_{CC3}$ = 5.0 V, unless otherwise noted.)

| Characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **HORIZONTAL TIME BASE SECTION (PLL #1)** | | | | |
| Fh Reference (Pin 14) Timing (See Figures 25, 27) | | | | |
| Rising edge from Sync center (Pins 1, 3) | – | 1.3 | – | µs |
| Rising edge from Sync center (Pins 26 to 29) | – | 650 | – | ns |
| Duty cycle | – | 50 | – | % |
| Sandcastle Output (Pin 35, see Figures 25, 27) | | | | Vdc |
| Output Voltage – Level 1 | 3.7 | 4.0 | 4.3 | |
| Output Voltage – Level 2 | 2.8 | 3.0 | 3.2 | |
| Output Voltage – Level 3 | – | 1.55 | – | |
| Output Voltage – Level 4 | – | 0.07 | – | |
| Rising edge from Sync center (Pins 1, 3) | – | –2.6 | – | µs |
| Rising edge from Sync center (Pins 26 to 29) | – | –3.3 | – | |
| High Time | – | 6.0 | – | |
| Level 2 Time | – | 5.0 | – | |
| Reference Voltage @ Pin 9 ($I_{ref}$ = 32 µA) | 1.0 | 1.2 | 1.4 | Vdc |
| **PHASE–LOCKED PIXEL CLOCK SECTION (PLL #2)** | | | | |
| VCO Frequency @ Pin 18 | | | | MHz |
| Minimum (Pin 16 = 1.6 V, $85–7 = 1) | – | 2.0 | 4.0 | |
| Maximum (Pin 16 = 4.0 V, $85–7= 0) | 30 | 45 | 60 | |
| VCO Up (Flag 19) Threshold Voltage @ Pin 16 | 1.5 | 1.7 | 1.9 | Vdc |
| VCO Down (Flag 20) Threshold Voltage @ Pin 16 | 3.1 | 3.3 | 3.5 | |
| VCO Control Voltage Range @ Pin 16 | 1.2 | – | 3.8 | Vdc |
| VCO Control Gain factor ($7FDAC = 00, $85–7 = 0) | 4.0 | 8.0 | 12 | MHz/V |
| Charge Pump Current (Pin 16) | 25 | 50 | 75 | µA |
| High Gain ($83–7 = 0) | | | | |
| Current Ratio | 0.3 | 0.4 | 0.5 | µA/µA |
| Low Gain–to–High Gain | | | | |
| Pixel Clock Output (Pin 18) (Load = 3 FAST TTL loads + 10 pF) | | | | |
| Output Voltage – High | – | 3.9 | – | Vdc |
| Output Voltage – Low | – | 0.15 | – | |
| Rise Time @ 50 MHz | – | 7.0 | – | ns |
| Rise Time @ 9.0 MHz | – | 17 | – | |
| Fall Time @ 50 MHz | – | 5.0 | – | |
| Fall Time @ 9.0 MHz | – | 8.0 | – | |
| 15 kHz Return (Pin 15) | | | | |
| Input Threshold Voltage | – | 1.5 | – | Vdc |
| Falling edge from Fh rising edge | – | 60 | – | ns |
| Minimum Input Low Time | 200 | – | – | |
| **VERTICAL DECODER** | | | | |
| Vertical Frequency Range | 43.3 | – | 122 | Hz |
| Vertical Sync Output | | | | |
| Saturation Voltage ($I_O$ = 800 µA) | – | 0.1 | 0.8 | V |
| Leakage Current @ 5.0 V (Output high) | – | – | 40 | µA |
| Timing from Sync polarity reversal to Pin 4 falling edge (See Figures 33, 34) | | | | µs |
| ($78–7 = 0) | 32 | 36 | 40 | |
| ($78–7 = 1) | 62 | 68 | 74 | |
| Vertical Sync Pulse Width (Pin 4, NTSC or PAL) | 490 | 500 | 510 | µs |
| Field Ident (Pin 7) Output Voltage – High ($I_O$ = –40 µA) | 2.4 | 4.5 | – | Vdc |
| Output Voltage – Low ($I_O$ = 800 µA) | – | 0.1 | 0.8 | |
| Timing | – | Fig. 33, 34 | – | |
| **HORIZONTAL SYNC SEPARATOR** | | | | |
| Sync Slicing Levels (Pins 1, 3) | – | 120 | – | mV |
| From Black Level (Pins 26 to 29) | – | 150 | – | |

9

## PIN FUNCTION DESCRIPTION

| FB QFP Pin | FN PLCC Pin | Representative Circuitry (Pin numbers refer to PLCC package) | Description (Pin numbers refer to PLCC package) |
|---|---|---|---|
| 39, 41 | 1, 3 |  | **Video Input 1 & 2** – Video 1 (Pin 1) and Video 2 (Pin 3) are composite video inputs. Either can be NTSC or PAL. Input impedance is high, termination must be external. Also used for the luma and chroma components of an S–VHS signal. Selection of these inputs is done by software. External components protect against ESD and noise. |
| 40 | 2 |  | **ACC Filter** – A 0.1 µF capacitor at this pin filters the feedback loop of the chroma automatic gain control amplifier. Input chroma burst amplitude can be between 30 and 600 mVpp. |
| 42 | 4 |  | **Vertical Sync Output** – An open collector output requiring an external pull–up. Output is an active low pulse, 500 µs wide, occurring each field. Timing of this pulse depends on Bit $78–7. |
| 43 | 5 |  | **SCL** – Clock for the $I^2C$ bus interface. See Appendix C for specifications. Maximum frequency is 100 kHz. |
| 44 | 6 |  | **SDL** – Bidirectional data line for the $I^2C$ bus interface. As an output, it is an open collector. (Write Address $8A, Read Address $8B) |
| 1 | 7 |  | **Field ID** – TTL level output indicating Field 1 or Field 2. Polarity depends on state of Bit $78–7 (Vertical Sync Delay). See Table 11 and Figure 33 and 34. |
| 2 | 8 | (Same as Pin 7) | **Burst Gate** – TTL level output used for external clamps, as well as internally. Pulse is active high, ≈ 3.5 µs wide, with the rising edge ≈ 3.0 µs after center of selected incoming sync pulse. |
| 3 | 9 |  | **Reference Current Input** – Current supplied to this pin, typically 32 µA from 5.0 V through a 110 kΩ resistor, is the reference current for the calibration circuit. Noise filtering should be done at the pin. Voltage at this pin is typically 1.2 V. |
| 4 | 10 | (See power distribution diagram at the end of this section.) | **Quiet Ground** – Ground for the horizontal PLL filter (PLL #1) at Pin 11. |

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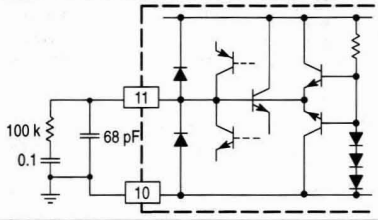
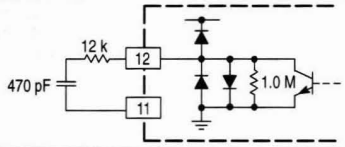
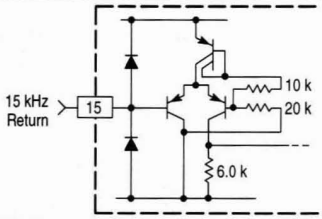
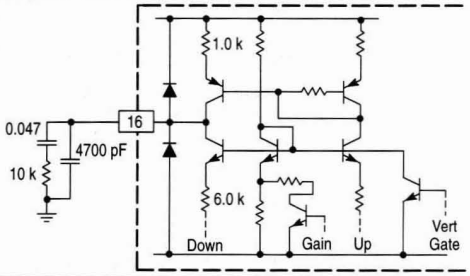
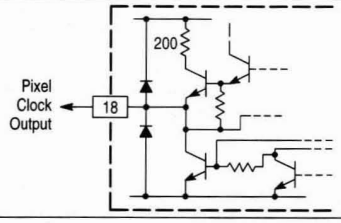
**PIN FUNCTION DESCRIPTION (continued)**

| FB QFP Pin | FN PLCC Pin | Representative Circuitry (Pin numbers refer to PLCC package) | Description (Pin numbers refer to PLCC package) |
|---|---|---|---|
| 5 | 11 |  | **H Filter** – Components at this pin filter the output of the phase detector of PLL #1. This PLL becomes phase–locked to the selected incoming horizontal sync. External component values are valid for NTSC and PAL systems. |
| 6 | 12 |  | **H Filter Switch** – An internal switch–to–ground which permits altering the filtering action of the components at Pin 11. |
| 7 | 13 | (Same as Pin 7) | **16 Fh/$C_{Sync}$** – A TTL level output from PLL #1. This pin provides either a square wave equal to Fh x 16 (≈ 250 kHz), or composite sync, depending on the setting of Bit $85–6. |
| 8 | 14 | (Same as Pin 7) | **Fh Reference** – A TTL square wave output which is phase–locked to the selected incoming horizontal sync. The rising edge occurs ≈ 1.3 µs after sync center. |
| 9 | 15 |  | **15 kHz Return** – This TTL input receives the output of an external frequency divider which is part of PLL #2 (Pixel Clock PLL). This signal will be phase and frequency–locked to the Fh signal at Pin 14. If PLL #2 is not used, this pin should be connected to a 5.0 V supply. |
| 10 | 16 |  | **PLL #2 Filter** – Components at this pin filter the output of the phase detector of PLL 2. This PLL becomes phase–locked to the Fh signal at Pin 14. Recommended values for filter components are shown. External components should be connected to ground at Pin 17. If PLL #2 is not used, this pin should be grounded. |
| 11 | 17 | (See power distribution diagram at the end of this section.) | **Gnd3** – Ground for the high frequency PLL #2. Signals at Pins 15 to 19 should be referenced to this ground. |
| 12 | 18 |  | **Pixel Clock Output** – Sampling clock output (TTL) for external A/D converters, and for the external frequency divider. Frequency range at this pin is 6.0 to 40 MHz. |

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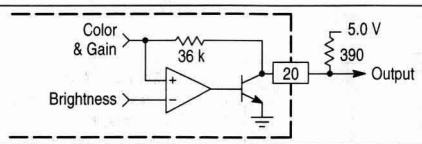
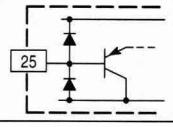
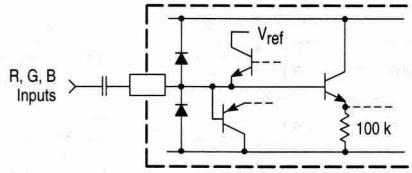
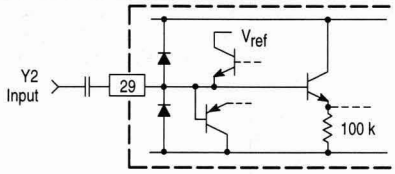
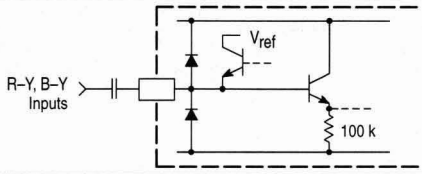
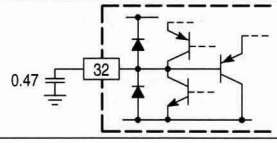
**PIN FUNCTION DESCRIPTION (continued)**

| FB QFP Pin | FN PLCC Pin | Representative Circuitry (Pin numbers refer to PLCC package) | Description (Pin numbers refer to PLCC package) |
|---|---|---|---|
| 13 | 19 | (See power distribution diagram at the end of this section.) | **$V_{CC3}$** – A 5.0 V supply (±5%), for the high frequency PLL #2. Decoupling must be provided from this pin to Pin 17. Ripple on this pin will affect pixel clock jitter. |
| 14 | 20 |  | **R/V Output** – Red (in RGB mode), or R–Y (in YUV mode), output from the color difference stage. A pull–up (390 Ω) to 5.0 V is required. Blank level is ≈ 1.4 Vdc. Maximum amplitude is ≈ 3.0 Vpp, black–to–white. |
| 15 | 21 | (Same as Pin 20) | **G/Y Output** – Green (in RGB mode), or Y (in YUV mode), output from the color difference stage (same as Pin 20). |
| 16 | 22 | (Same as Pin 20) | **B/U Output** – Blue (in RGB mode), or B–Y (in YUV mode), output from the color difference stage (same as Pin 20). |
| 17 | 23 | (See power distribution diagram at the end of this section.) | **$V_{CC2}$** – A 5.0 V supply (±5%), for the color difference stage. Decoupling must be provided from this pin to Pin 24. |
| 18 | 24 | (See power distribution diagram at the end of this section.) | **Gnd2** – Ground for the color difference stage. Signals at Pins 20 to 31 should be referenced to this pin. |
| 19 | 25 |  | **FC** – Fast Commutate switch. Taking this pin high (TTL level) connects the RGB inputs (Pins 26 to 28) to the RGB outputs (Pins 20 to 22), permitting an overlay function. The switch can be disabled in software (Bit $80–7). |
| 20, 21, 22 | 26, 27, 28 |  | **Blue (26), Green (27), Red (28) Inputs** – Inputs to the color difference stage. Designed to accept standard analog video levels, these input pins have a clamp and sync separator. They are selected with Pin 25 or in software (Bit $80–7). |
| 23 | 29 |  | **Y2 Input** – Luma #2/Composite sync input. This luma input to the color difference stage is used in conjunction with auxiliary color difference inputs, and/or as a sync input. Clamp and sync separator are provided. |
| 24, 25 | 30, 31 |  | **B–Y (30), R–Y (31) Inputs** – Inputs to the color difference stage. Designed for standard color difference levels, these inputs can be capacitor coupled from the color difference outputs, from a delay line, or an auxiliary signal source. Input clamp is provided. |
| 26 | 32 |  | **Y1 Clamp** – A 0.47 μF capacitor at this pin provides clamping for the Luma #1 output. |

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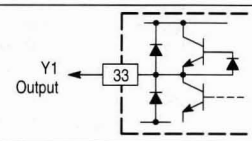
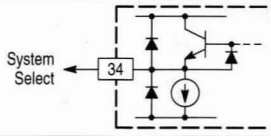
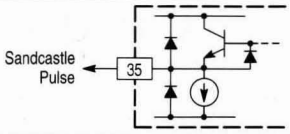
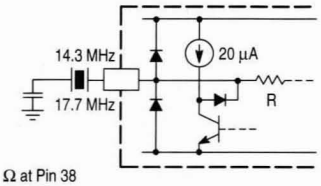
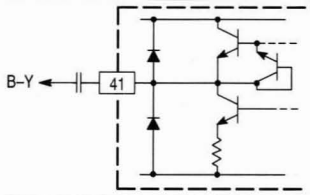
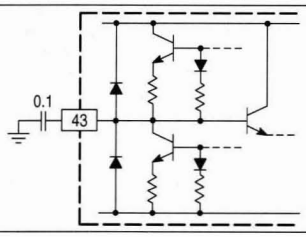
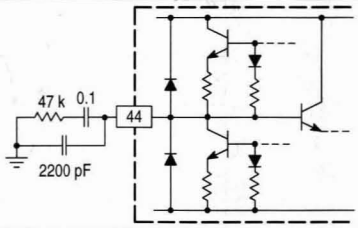
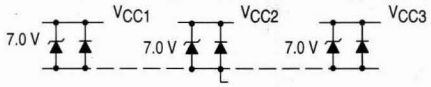
## PIN FUNCTION DESCRIPTION (continued)

| FB QFP Pin | FN PLCC Pin | Representative Circuitry (Pin numbers refer to PLCC package) | Description (Pin numbers refer to PLCC package) |
|---|---|---|---|
| 27 | 33 |  | **Y1 Output** – Luma #1 output. This output from the PAL/NTSC/S–VHS decoder is the luma component of the decoded composite video at Pin 1 or 3. It is internally directed to the color difference stage. |
| 28 | 34 |  | **System Select** – A multi–level dc output which indicates the color decoding system to which the PAL/NTSC detector is set by the software. This output is used by the MC44140 chroma delay line. |
| 29 | 35 |  | **Sandcastle Pulse** – A multi–level timing pulse output used by the MC44140 chroma delay line. This pulse encompasses the horizontal sync and burst time. |
| 30, 32 | 36, 38 |  <br>R = 400 Ω at Pin 38<br>R = 300 Ω at Pin 36 | **Xtal 2 (36), Xtal 1 (38)** – Designed for connection of 4x subcarrier color crystals. Selection is done in software. The selected frequency is used by the PAL/NTSC detector; system identifier; all notches and traps; delay lines; and the horizontal calibration circuit.<br>The crystal frequency should be:<br>14.3 MHz at Pin 36 for NTSC,<br>17.7 MHz at Pin 38 for PAL.<br><br>(See Table 17 for crystal specifications) |
| 31 | 37 | | **No Connect** – This pin is to be left open. |
| 33 | 39 | (See power distribution diagram at the end of this section.) | **Ground 1** – Ground for all sections except PLL #2 and the color difference stage. |
| 34 | 40 | (See power distribution diagram at the end of this section.) | $V_{CC1}$ – A 5.0 V (±5%), supply to all sections except PLL #2 and the color difference stage. |
| 35 | 41 |  | **B–Y Output** – Output from the PAL/NTSC decoder, it is typically capacitor–coupled to a delay line or to the B–Y input. This pin is clamped, and filtered at the color subcarrier frequency, 2x, and 8x that frequency. |
| 36 | 42 | (Same as Pin 41) | **R–Y Output** – Output from the PAL/NTSC decoder. |
| 37 | 43 |  | **Ident Filter** – A 0.1 µF capacitor filters the system identification circuit in the NTSC/PAL decoder. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| FB QFP Pin | FN PLCC Pin | Representative Circuitry (Pin numbers refer to PLCC package) | Description (Pin numbers refer to PLCC package) |
|---|---|---|---|
| 38 | 44 |  | **Crystal PLL Filter** – Components at this pin filter the PLL for the crystal chroma oscillator circuit. |
| 4, 11, 13, 17, 18, 33, 34 | 10, 17, 19, 23, 24, 39, 40 |  (Dashed lines indicate substrate connection.) | **Power Distribution** – The three $V_{CC}$ pins must be externally connected to 5.0 V (±5%) supply. The four grounds must be externally tied together, preferably to a ground plane. |

9

## Luma Frequency Response (14.3 MHz) Crystal, (4.5 MHz) Sound Trap

**Figure 2. Composite Video Mode**

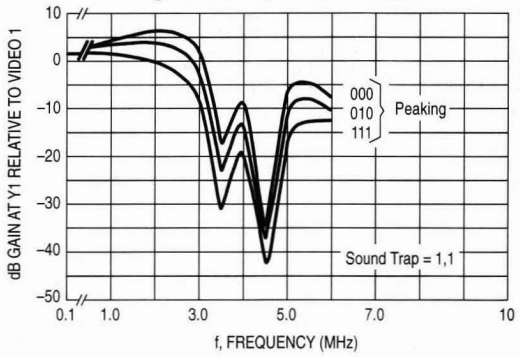
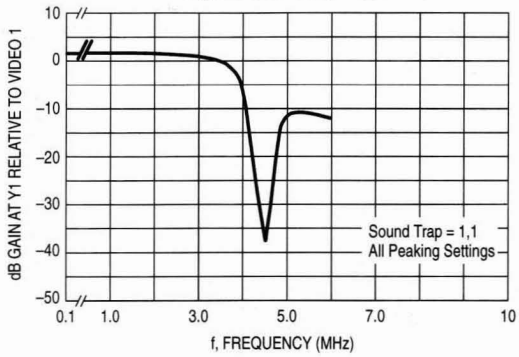



**Figure 3. S–VHS Mode**




## Luma Frequency Response (17.7 MHz) Crystal, (5.5 MHz) Sound Trap

**Figure 4. Composite Video Mode**

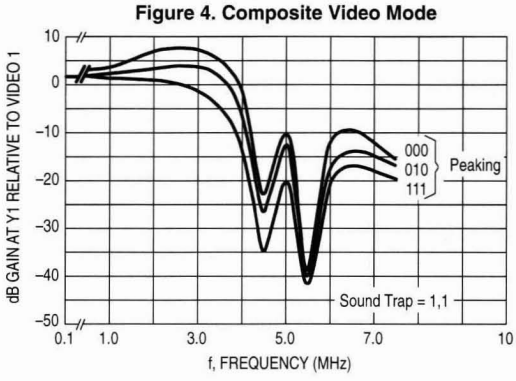
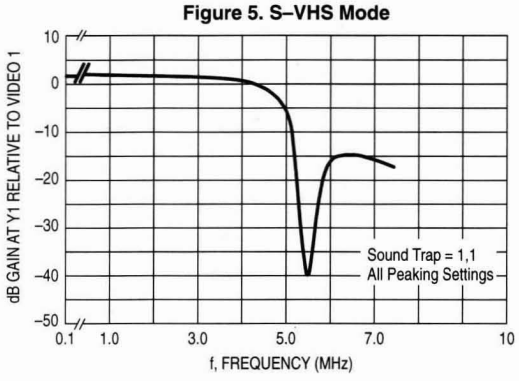



**Figure 5. S–VHS Mode**




## Luma Frequency Response (17.7 MHz) Crystal, (5.5/5.75 MHz) Sound Trap

**Figure 6. Composite Video Mode**

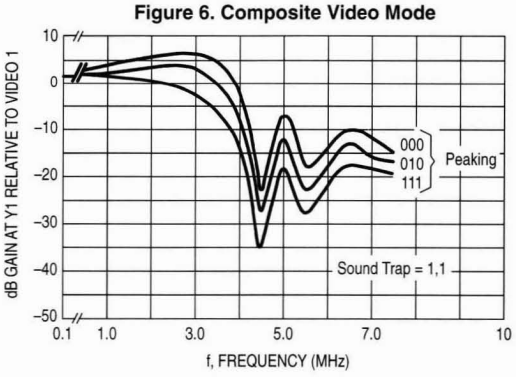
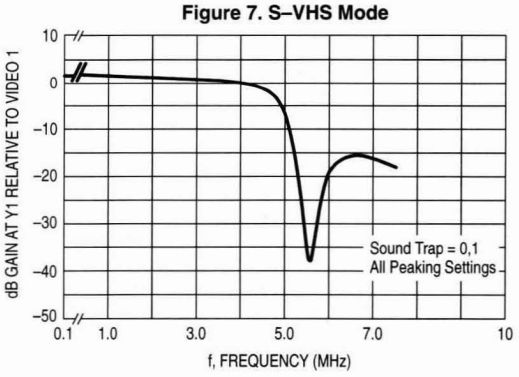



**Figure 7. S–VHS Mode**




9

## Luma Frequency Response (17.7 MHz) Crystal, (6.0 MHz) Sound Trap

**Figure 8. Composite Video Mode**

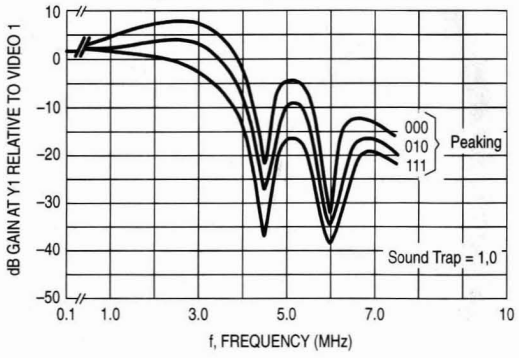
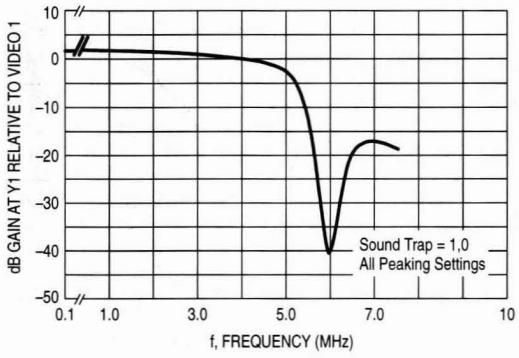



**Figure 9. S–VHS Mode**




## Luma Frequency Response (17.7 MHz) Crystal, (6.5 MHz) Sound Trap

**Figure 10. Composite Video Mode**

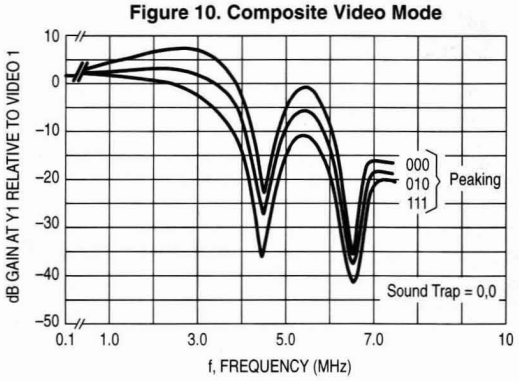



**Figure 11. S–VHS Mode**

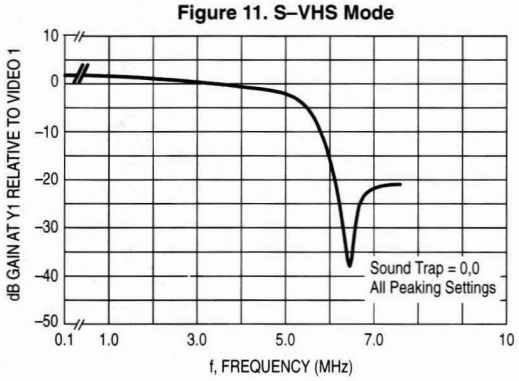



**Figure 12. (3.58 MHz) Chroma Notch**

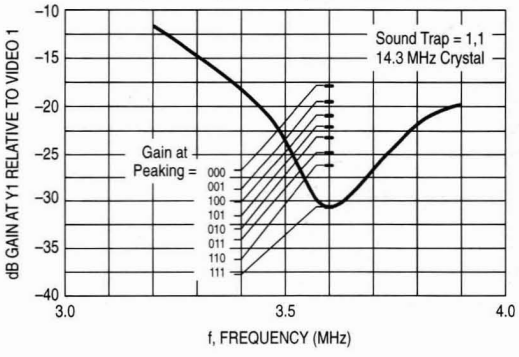
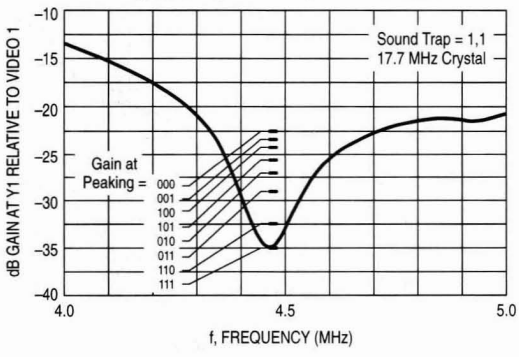



**Figure 13. (4.43 MHz) Chroma Notch**




9

## (4.5 MHz) Sound Trap

**Figure 14. Composite Video Mode**

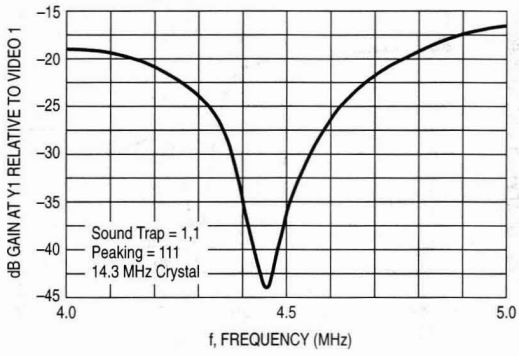
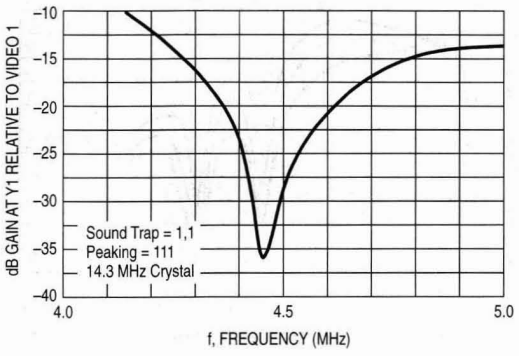



**Figure 15. S–VHS Mode**




## (5.5 MHz) Sound Trap

**Figure 16. Composite Video Mode**

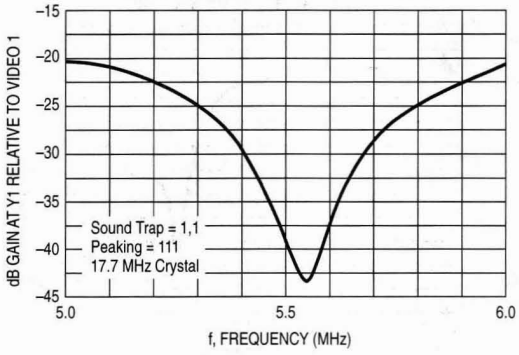
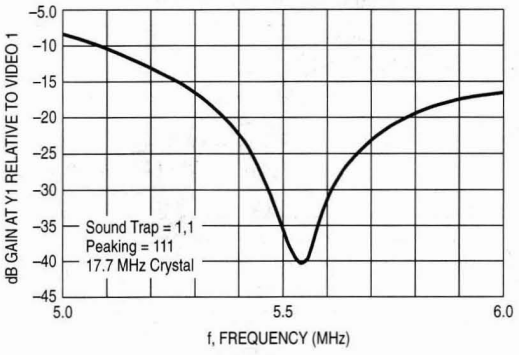



**Figure 17. S–VHS Mode**




## (5.5 + 5.75 MHz) Sound Trap

**Figure 18. Composite Video Mode**

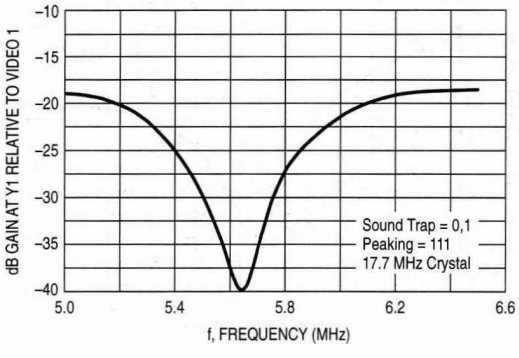
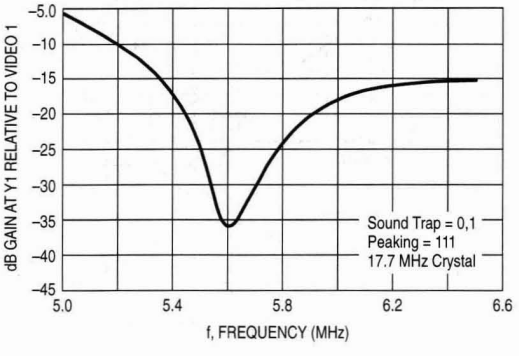



**Figure 19. S–VHS Mode**



**(6.0 MHz) Sound Trap**

**Figure 20. Composite Video Mode**

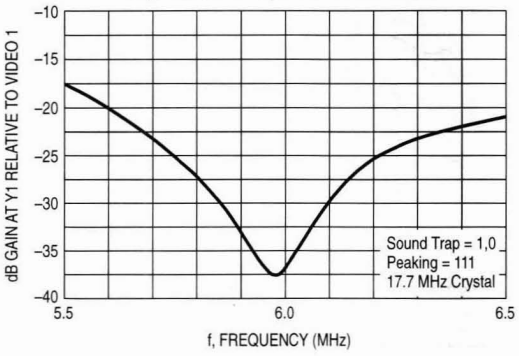
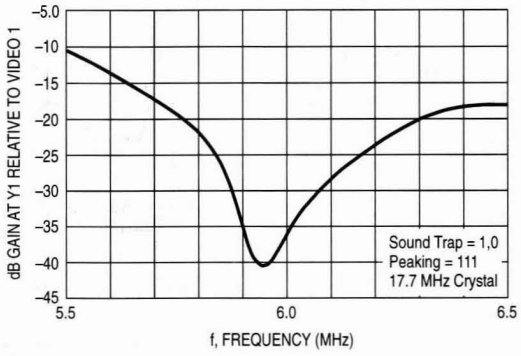



**Figure 21. S–VHS Mode**




**(6.5 MHz) Sound Trap**

**Figure 22. Composite Video Mode**

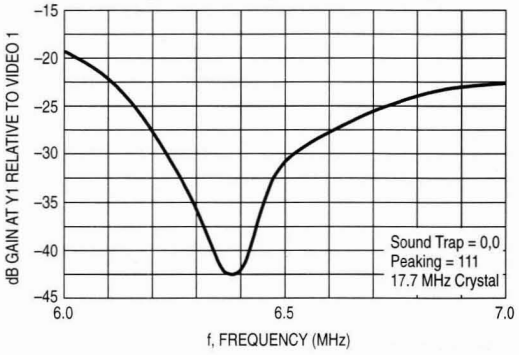



**Figure 23. S–VHS Mode**

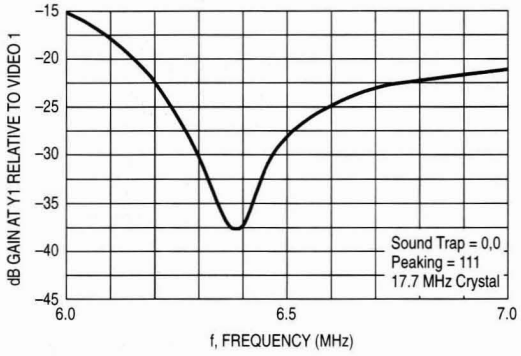



**Figure 24. FC Input Current**

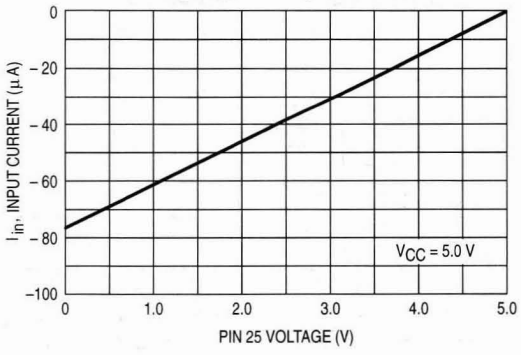



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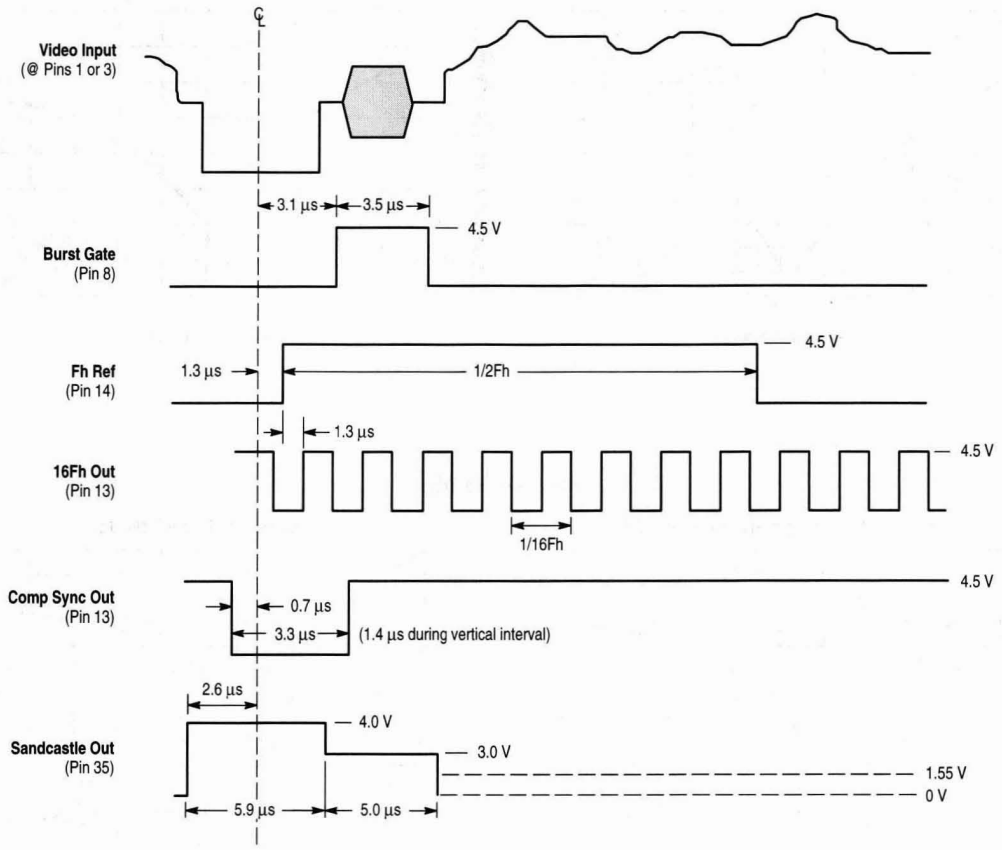
**Figure 25. Horizontal PLL1 Timing/Composite Video Inputs**




**NOTE:** In above waveforms, all timing is referenced to the **center** of the incoming Sync Pulse at Pin 1 or 3.
Above timings based on a 4.6 µs wide sync pulse.
Lower two levels of Sandcastle output alternate, based on video system in effect.
All timings are nominal, and apply to both PAL and NTSC signals.

**Figure 26. Horizontal PLL1 Noise Gate and Filter Pin**

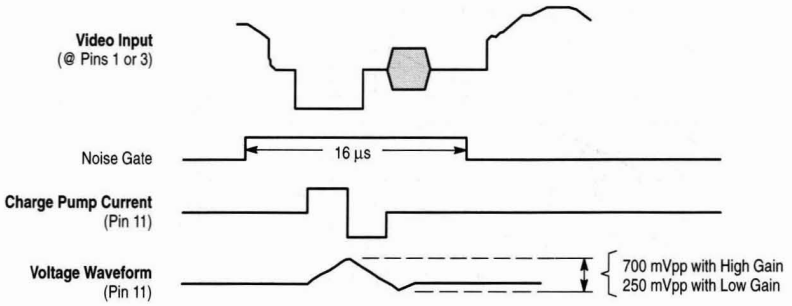
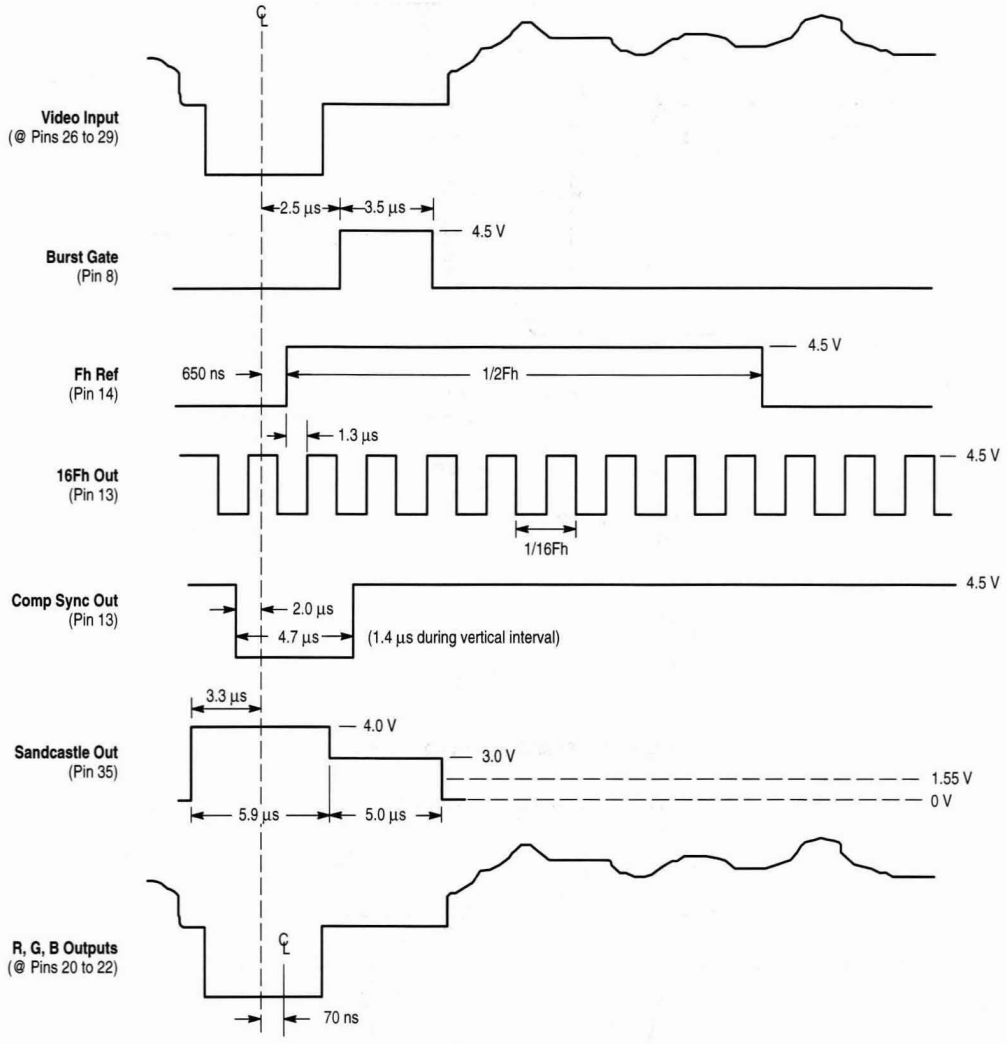


**Figure 27. Horizontal PLL1 Timing/R, G, B and Y2 Inputs**




**NOTE:** In above waveforms, all timing is referenced to the **center** of the incoming Sync Pulse at Pin 26 to 28, or 29.
Above timings based on a 4.6 µs wide sync pulse.
Lower two levels of Sandcastle output alternate, based on video system in effect.

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**Figure 28. System Timing/Video Inputs to RGB Outputs**

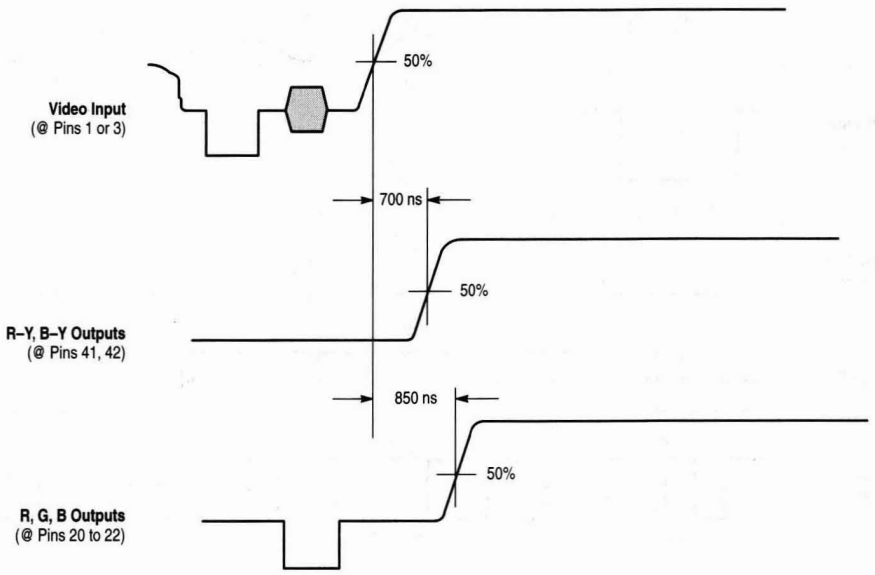


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**Figure 29. Fast Commutate Timing**

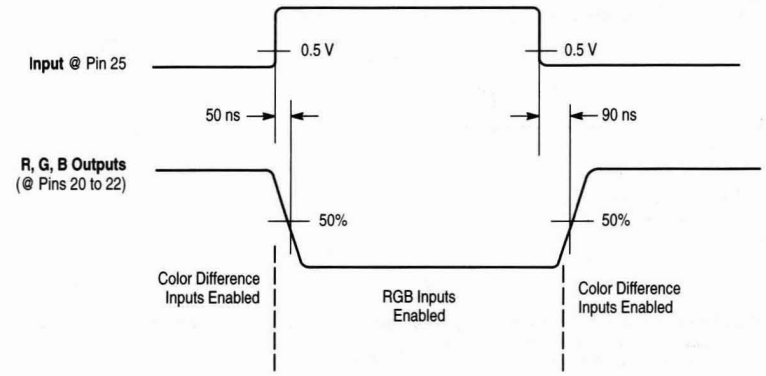

**Figure 30. Horizontal Outputs versus Fields (NTSC System)**

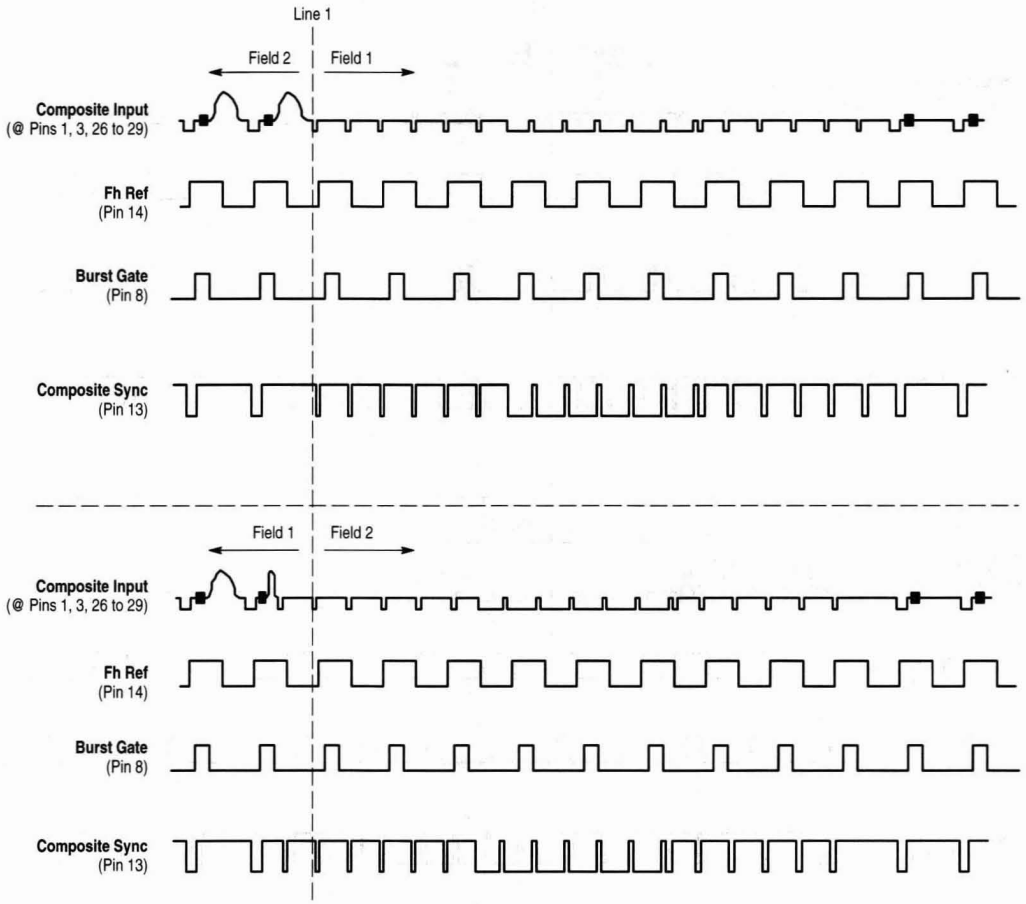


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**Figure 31. Horizontal Outputs versus Fields (PAL System)**

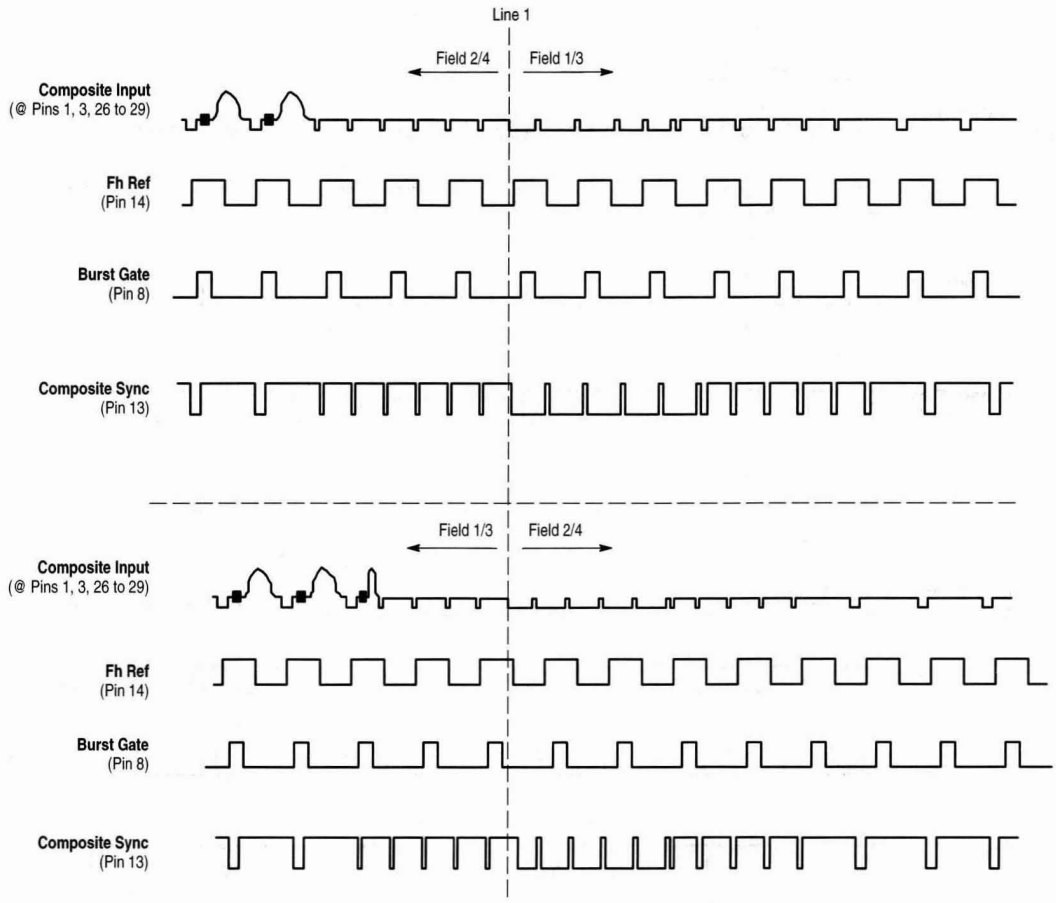


**Figure 32. Horizontal PLL2 Timing**

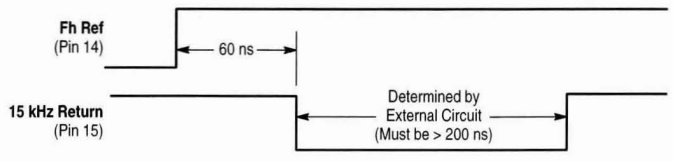

**Figure 33. Vertical Timing (NTSC System)**

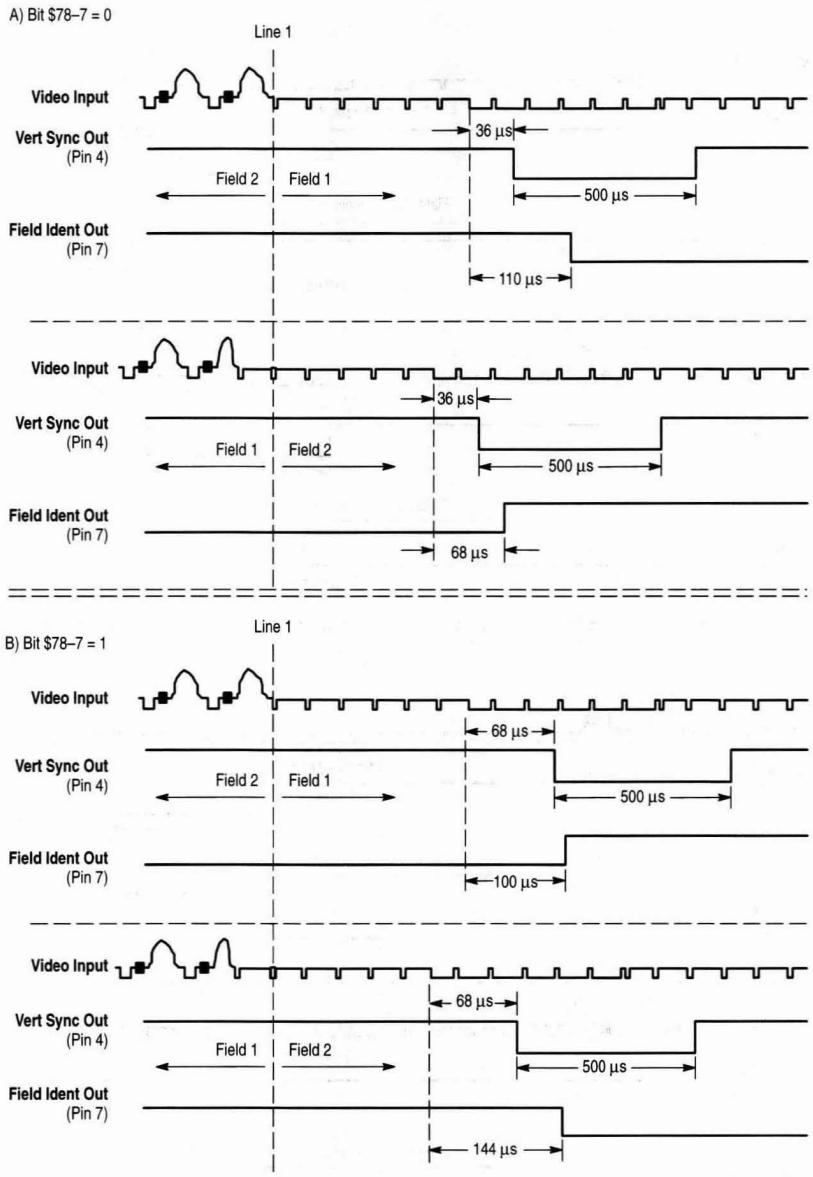


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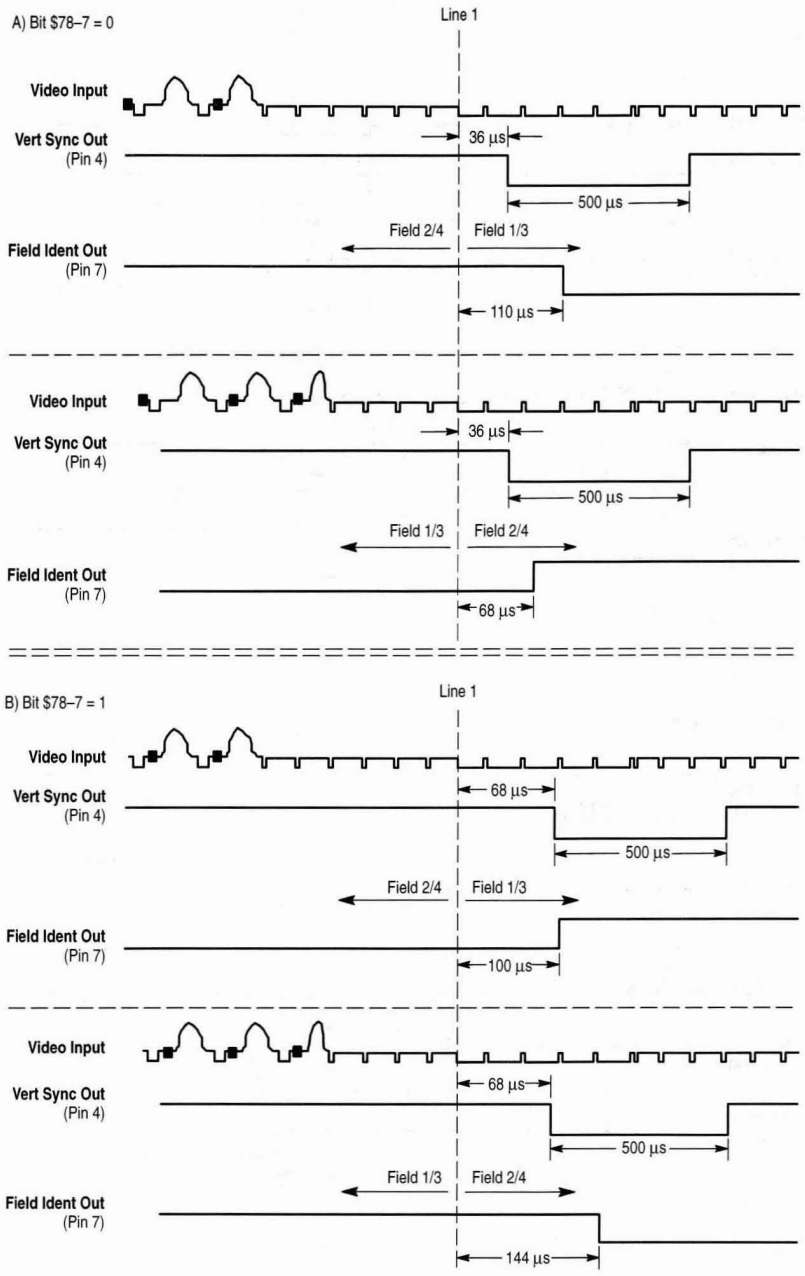
**Figure 34. Vertical Timing (PAL System)**

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## FUNCTIONAL DESCRIPTION

### Introduction

The MC44011, a member of the MC44000 Chroma 4 family, is a composite video decoder which has been tailored for applications involving multimedia, picture–in–picture, and frame storage (although not limited to those applications). The first stage of the MC44011 provides color difference signals (R–Y, B–Y, and Y) from one of two (selectable) composite video inputs, which are designed to receive PAL, NTSC, and S–VHS (Y,C) signals. The second stage provides either RGB or YUV outputs from the first stage's signals, or from a separate (internally selectable) set of RGB inputs, permitting an overlay function to be performed. Adjustments can be made to saturation; hue; brightness; contrast; brightness balance; contrast balance; U and V bias; subcarrier phase; and color difference gain ratio.

The above mentioned video decoding sections provide the necessary luma/delay function, as well as all necessary filters for sound traps, luma/chroma separation, luma peaking, and subcarrier rejection. External tank circuits and luma delay lines are not needed. For PAL applications, the MC44140 chroma delay line provides the necessary line–by–line corrections to the color difference signals required by that system.

The MC44011 provides a pixel clock to set the sampling rate of external A/D converters. This pixel clock, and other horizontal frequency related output signals, are phase–locked to the incoming sync. The VCO's gain is adjustable for optimum performance. The MC44011 also provides vertical sync and field identification (Field 1, Field 2) outputs.

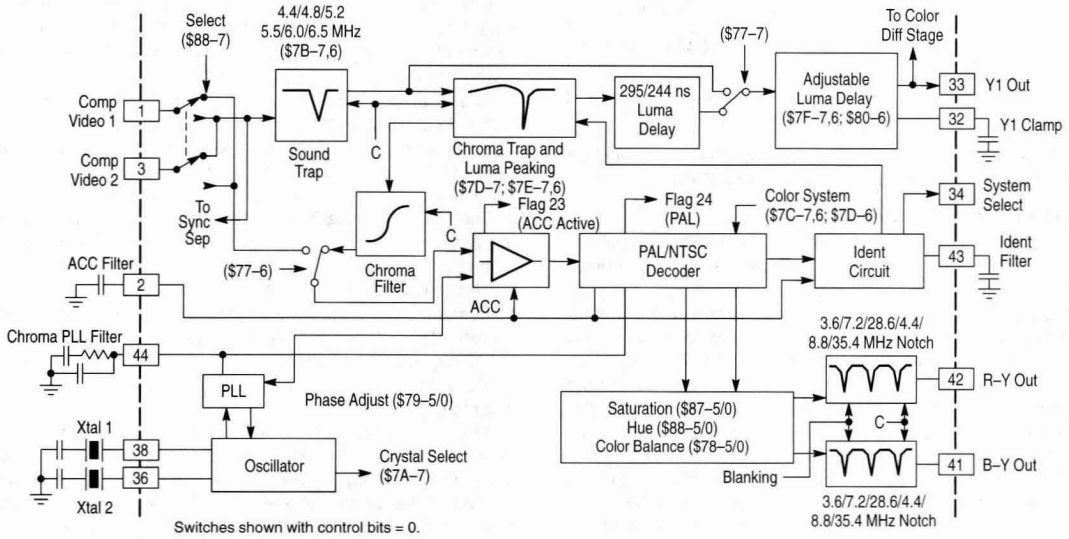
Selection of the various inputs, outputs, and functions, as well as the adjustments, is done by means of a two–wire I²C interface. The basic procedure requires the microprocessor system to read the internal flags of the MC44011, and then set the internal registers appropriately. This I²C interface eliminates the need for manual controls (potentiometers) and external switches. All of the external components for the MC44011, except for the two crystals, are standard value resistors and capacitors, and can be non–precision.

*(The DACs mentioned in the following description are 6–bits wide. The settings mentioned for them are given in decimal values of 00 to 63. These are not hex values.)*

### PAL/NTSC/S–VHS Decoder

A block diagram of this decoder section is shown in Figure 35. This section's function is to take the incoming composite video (at Pins 1 or 3), separate it into luma and chroma information, determine if the signal is PAL or NTSC (for the flags), and then provide color difference and luma signals at the outputs. If the input is S–VHS, the luma/chroma separation is bypassed, but the other functions are still in effect.

**Figure 35. PAL/NTSC/S–VHS Decoder Block Diagram**



### Inputs

The inputs at Pins 1 and 3 are high impedance inputs designed to accept standard 1.0 Vpp positive video signals (with negative going sync). The inputs are to be capacitor–coupled so as not to upset the internal dc bias. When normal composite video is applied, the desired input is selected by Bit $88–7. Bits $77–6 and $77–7 must be set to 0 so that their switches are as shown in Figure 35. The selected signal passes through the sound trap, and is then separated by the chroma trap and the chroma (high pass) filter.

When S–VHS signals (Y,C) are applied to the two inputs, Bit $88–7 is used to direct the luma information to the sound trap, and the chroma information to the ACC circuit (Bit $77–6 must be set to a Logic 1). Bit $77–7 is normally set to a Logic 1 in this mode to bypass the first luma delay line and the chroma trap, but it can be left 0 if the additional delay is desired.

### Sound Trap

The sound trap will filter out any residual sound subcarrier at the frequency selected by control bits T1 and T2 according to Table 3. The accuracy of the notch frequency is directly related to the selected crystal frequency.

**Table 3. Sound Trap Frequency**

| Crystal Frequency | T1 ($7B–7) | T1 ($7B–6) | Notch Frequency |
|---|---|---|---|
| 17.73 MHZ | 0 | 0 | 6.5 MHz |
| | 0 | 1 | 5.5 + 5.75 MHz |
| | 1 | 0 | 6.0 MHz |
| | 1 | 1 | 5.5 MHz |
| 14.32 MHz | 0 | 0 | 5.25 MHz |
| | 0 | 1 | 4.44 + 4.64 MHz |
| | 1 | 0 | 4.84 MHz |
| | 1 | 1 | 4.44 MHz |

Code 01 (for T1, T2) is used to widen the band rejection where stereo is in use. Typical rejection is 30 dB.

### ACC and PAL/NTSC Decoder

The chroma filter bandpass characteristics (3.58 or 4.43 MHz) is determined by the selected crystal. The output of the chroma filter is sent to the ACC circuit which detects the burst signal, and provides automatic gain control once the crystal oscillator has achieved phase lock–up to the burst. The dc voltage at Pin 2 is ≈ 1.5 to 2.0 V. This will occur if the burst amplitude exceeds 30 mVpp, and if the correct crystal is selected (Bit $7A–7). A 17.734472 MHz crystal is required for PAL, and a 14.31818 MHz crystal is required for NTSC. When Flag 23 is high, it indicates that the crystal's PLL has locked up, and the ACC circuit is active, providing automatic gain control. A small amount of phase adjustment (≈ ±5°) of the crystal PLL, for color correction, can be made with control DAC $79–5/0. Pin 2 is the filter for the ACC loop, and Pin 44 is the filter for the crystal oscillator PLL.

The PAL/NTSC decoder then determines if the signal is PAL or NTSC by looking for the alternating phase characteristic of the PAL burst. When Flag 24 is high, PAL has been detected. Bits SSA, SSB, SSC, and SSD (Table 4) must then be sent to the decoder to set the appropriate decoding method.

**Table 4. Color System Select**

| SSA ($7C–6) | SSB ($7D–6) | SSC ($7C–7) | SSD ($7A–6) | Color System |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | Not Used |
| 0 | 1 | 0 | 0 | PAL |
| 1 | 0 | 0 | 0 | NTSC |
| 1 | 1 | 0 | 0 | Color Kill |
| X | X | 1 | 0 | External |

Upon receiving the SSA to SSD bits, the decoder provides the correct color difference signals, and with the Identification circuit, provides the correct level at the System Select output (Pin 34). This output is used by the MC44140 delay line.

The color kill setting (SSA = SSB = 1) should be used when the ACC flag is 0, when the color system cannot be properly determined, or when it is desired to have a black–and–white output (the ACC circuit and flag will still function if the input signal has a burst signal). The "External" setting (SSC = 1) is used when an external (alternate) source of color difference signals are applied to the MC44140 delay line. (See Miscellaneous Applications Information for more details.)

### Color Difference Controls and Outputs

The color difference signals (R–Y, B–Y) from the PAL/NTSC decoder are directed to the saturation, hue and color balance controls, and then through a series of notch filters before being output at Pins 41 and 42. Blanking and clamping are applied to these outputs.

The saturation control DAC($87–5/0) varies the amplitude of the two signals from 0 Vpp (DAC setting = 00), to a maximum of ≈ 1.8 Vpp (at a DAC setting of 63). The maximum amplitude (without clipping) is ≈ 1.5 Vpp, but a nominal setting is ≈ 1.3 Vpp at a DAC setting of 15.

The hue control ($88–5/0) varies the relative amplitude of the two signals to provide a hue adjustment. The nominal setting for this DAC is 32.

The color balance control ($78–5/0) provides a fine adjustment of the relative amplitude of the two outputs. This provides for a more accurate color setting, particularly when NTSC signals are decoded. The nominal setting for this DAC is 32, and should be adjusted before the hue control is adjusted.

The notch filters provide filtering at the color burst frequency, and at 2x and 8x that frequency. Additionally, blanking and clamping (derived from the horizontal PLL) are applied to the signals at this stage. The nominal output dc level is ≈ 2.0 to 2.5 Vdc, and the load applied to these outputs should be >10 kΩ. Sync is not present on these outputs.

### Luma Peaking, Delay Line, and Y1 Output

When composite video is applied, the luma information extracted in the chroma trap is then applied to a stage which allows peaking at ≈ 3.0 MHz with the 17.7 MHz crystal (≈ 2.2 MHz with the 14.3 MHz crystal). The amount of peaking at Y1 is with respect to the gain at the minimum peaking value (P1, P2, P3 = 111), and is adjustable with Bits $7D–7, and $7E–7,6 according to Table 5.

The luma delay lines allow for adjustment of that delay so as to correspond to the chroma delay through this section. Table 6 indicates the amount of delay using the D1–D3 bits ($7F–7,6, and $80–6). The delay indicated is the total delay from Pin 1 or 3 to the Y1 output at Pin 33. The amount of delay depends on whether Composite Video is applied, or YC signals (S–VHS) are applied.

The output impedance at Y1 is ≈ 300 Ω, and the black level clamp is at ≈ 1.1 V. Sync is present on this output. Y1 is also internally routed to the color difference stage.

**Table 5. Luma Peaking**

| P1 ($7D–7) | P2 ($7E–6) | P3 ($7E–7) | Y1 Peaking |
|---|---|---|---|
| 0 | 0 | 0 | 9.5 dB |
| 0 | 0 | 1 | 8.5 |
| 1 | 0 | 0 | 7.7 |
| 1 | 0 | 1 | 6.5 |
| 0 | 1 | 0 | 5.3 |
| 0 | 1 | 1 | 3.8 |
| 1 | 1 | 0 | 2.2 |
| 1 | 1 | 1 | 0 |

17.7 MHz Crystal, 6.5 MHz Sound Trap, Composite Video Mode

**Table 6. Luma Delay**

| D1 ($7F–6) | D2 ($80–6) | D3 ($7F–7) | 14.3 MHz Crystal | | 17.7 MHz Crystal | |
|---|---|---|---|---|---|---|
| | | | Comp. Video ($77–7 = 0) | S–VHS ($77–7 = 1) | Composite Video ($77–7 = 0) | S–VHS ($77–7 = 1) |
| 0 | 0 | 0 | 690 ns | 395 ns | 594 ns | 350 ns |
| 0 | 0 | 1 | 760 | 465 | 650 | 406 |
| 0 | 1 | 0 | 830 | 535 | 707 | 463 |
| 0 | 1 | 1 | 900 | 605 | 763 | 519 |
| 1 | 0 | 0 | 970 | 675 | 819 | 575 |
| 1 | 0 | 1 | 1040 | 745 | 876 | 632 |
| 1 | 1 | 0 | 970 | 675 | 819 | 575 |
| 1 | 1 | 1 | 1040 | 745 | 876 | 632 |

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### Color Difference Stage and RGB/YUV Outputs

A block diagram of this section is shown in Figure 36. This section's function is to take the color difference input signals (Pins 30, 31), or the RGB inputs (Pins 26 to 28), and output the information at Pins 20 to 22 as either RGB or YUV.

The inputs (on the left side of Figure 36) are analog RGB, or color difference signals (R–Y and B–Y) with Y1 or Y2 as the luma component. Pin 25 (Fast Commutate) is a logic level input, used in conjunction with $\overline{\text{RGB EN}}$ (Bit $80–7), to select the RGB inputs or the color difference inputs. The outputs (Pins 20 to 22) are either RGB or YUV, selected with Bit $82–7. The bit numbers adjacent to the various switches and gates indicate the bits used to control those functions. Table 7 indicates the modes of operation.

**Table 7. Color Difference Input/Output Selection**

| FC | $\overline{\text{RGB EN}}$ $80–7 | YX EN $82–6 | YUV EN $82–7 | Function |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | RGB inputs, RGB outputs, no saturation control |
| 1 | 0 | 1 | 0 | RGB inputs, RGB outputs, with saturation control |
| 1 | 0 | 1 | 1 | RGB inputs, YUV outputs, with saturation control |
| 1 | 0 | 0 | 1 | Not usable |
| FC Low and/or $\overline{\text{RGB EN}}$ Hi | | X | 0 | R–Y, B–Y inputs, RGB outputs. Y1 or Y2 must be selected |
| FC Low and/or $\overline{\text{RGB EN}}$ Hi | | X | 1 | R–Y, B–Y inputs, YUV outputs. Y1 or Y2 must be selected |

In addition to Table 7, the following guidelines apply:

a. To select the RGB inputs, both FC must be high and $\overline{\text{RGB EN}}$ must be low. Therefore, the RGB inputs can be selected either by the I²C bus by leaving FC permanently high, or by the FC input by leaving Bit $80–7 permanently low. For overlay functions, where high speed, well controlled switching is necessary, the FC pin must be the controlling input.

b. When the R–Y, B–Y inputs are selected, either Y1 or Y2 must be selected, and the other must be deselected. The YX input is automatically disabled in this mode.

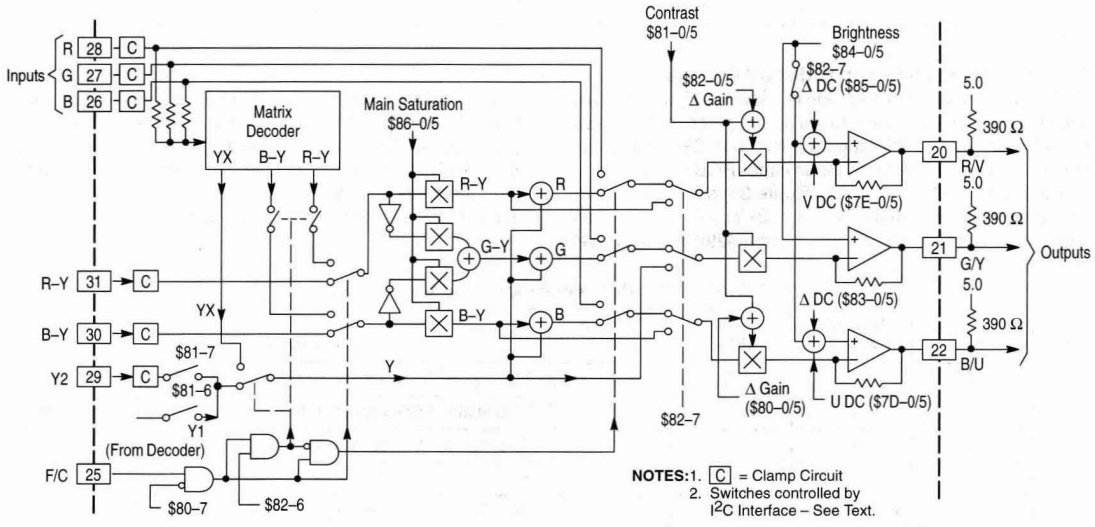
c. In applications where the color difference inputs are obtained from the NTSC/PAL decoder (from a composite video signal), Y1 is used. The Y2 input is normally used where alternately sourced color difference signals are applied, either through the MC44140 delay line, or through other external switching to Pins 30 and 31.

In Figure 36, the bit numbers followed by "–0/5" indicate DAC operated controls (contrast, brightness, etc.), which are controlled by the I²C bus. The DACs have 6–bit resolution, allowing 64 adjustment steps. Table 8 provides guidelines on the DAC operation.

**Table 8. DAC Operation – Color Difference Section**

| Function | Bits | RGB Outputs ($82–7 = 0) | YUV Outputs ($82–7 = 1) |
|---|---|---|---|
| Brightness | $84–0/5 | Affects dc black and maximum levels of the three outputs, but not the clamp level, nor the amplitude. | Affects dc black and white levels of the Y output only, but not the clamp level, nor the amplitude. |
| Δ DC – Red<br>Δ DC – Blue | $85–0/5<br>$83–0/5 | Fine tune the Red and Blue brightness levels. | Allows a small amount of color tint control (not to be confused with hue). |
| Contrast | $81–0/5 | Provides gain adjustment (black–to–white) of the three outputs. | Provides gain adjustment of the three outputs. |
| Δ Gain – Red<br>Δ Gain – Blue | $82–0/5<br>$80–0/5 | Fine tune the Red and Blue contrast levels. | Fine tune of the U and V gain levels. |
| V DC<br>U DC | $7E–0/5<br>$7D–0/5 | Must be set to 00. | Should nominally be set to 32. This sets the dc level of the U and V outputs at ≈ mid–scale. |
| Main Saturation | $86–0/5 | Affects color saturation, except when the RGB inputs bypass this section (YX EN = 0). | Affects color saturation levels of the UV outputs. Does not affect the Y output. |

**Figure 36. Color Difference Stage and Outputs**



The RGB and Y2 inputs are designed to accept standard 1.0 Vpp analog video signals. They are not designed for TTL level signals. The color difference inputs are designed to accept signals ranging up to 1.8 Vpp. All signals are to be capacitor–coupled as clamping is provided internally. Input impedance at these six pins is high.

For applications involving externally supplied color difference signals, sync can be supplied on the luma input (Y2), or it can be supplied separately at the RGB inputs. Where the color difference signals are obtained from the NTSC/PAL decoder, sync is provided to this section on the internal Y1 signal. See Sync Separator section for more details on injecting sync into the MC44011.

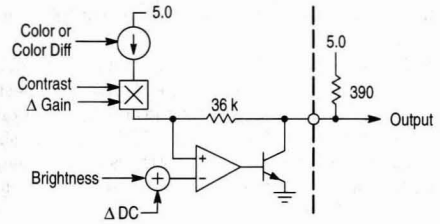
Sync is present on all three outputs in the RGB mode, and on the Y output only (Pin 21) in the YUV mode.

The Fast Commutate input (FC, Pin 25) is a logic level input with a threshold at ≈ 0.5 V. Input impedance is ≈ 67 kΩ, and the graph of Figure 24 shows the input current requirements. Propagation delay from the FC pin to the RGB/YUV outputs is ≈ 50 ns when enabling the RGB inputs, and ≈ 90 ns when disabling the inputs. (See Figure 29 Fast Commutate Timing diagram.) If Pin 25 is open, that is equivalent to a Logic 1, although good design practices dictate that inputs should never be left open. The voltage on this pin should not be allowed to go more than 0.5 V above $V_{CC2}$ or below ground.

The three outputs (Pins 20 to 22) are open–collector, requiring an external pull–up. A representative schematic is shown in Figure 37.

The output amplitude can be varied from 100 mVpp to 3.0 Vpp by use of the contrast and saturation controls. Any output load to ground should be kept larger than 1.0 kΩ. In the RGB mode, DACs $7D and $7E should be set to 00, which results in clamping levels of ≈ 1.4 Vdc. In the YUV mode, DACs $7D and $7E should be set to 00, which results in clamping levels of ≈ 1.4 Vdc. In the YUV mode, the DACs should be set to 32 to bias the U and V outputs to ≈ 2.3 V. The Y output clamp will remain at ≈ 1.4 V in the YUV mode.

**Figure 37. Output Stage**




### Horizontal PLL (PLL1)

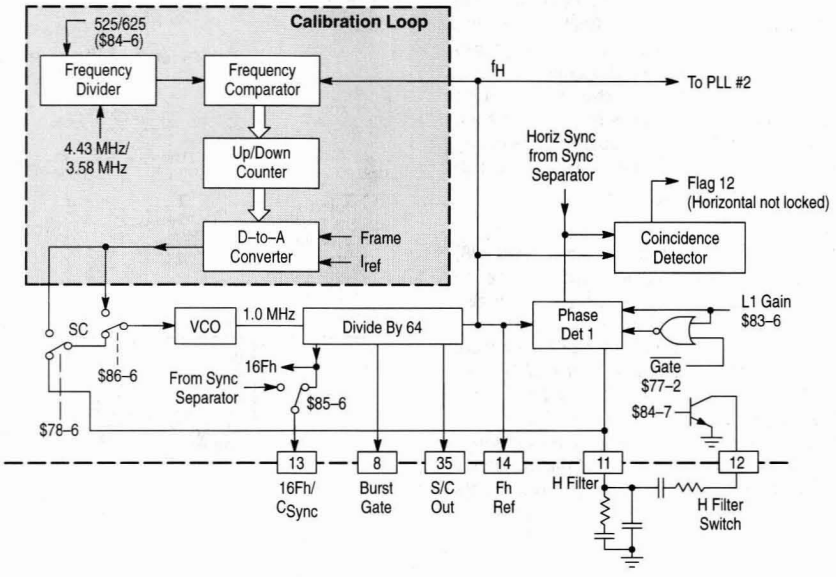
PLL1 (shown in Figure 38) provides several outputs which are phase–locked to the incoming horizontal sync. In normal operation, the two switches at the left side of Figure 38 are as shown, and (usually) the transistor at Pin 12 is off.

The phase detector compares the incoming sync (from the sync separator) to the frequency from the ÷ 64 block. The phase detector's output, filtered at Pin 11, controls the VCO to set the correct frequency (≈ 1.0 MHz) so that the output of the ÷ 64 is equal to the incoming horizontal frequency.

The line–locked outputs are:

1) **Fh Ref** (Pin 14) – A square wave, TTL levels, at the horizontal frequency, and phase–locked to the sync source according to the timing diagram of Figures 25 and 27.
2) **Burst Gate** (Pin 8) – This is a positive going pulse, TTL levels, coincident with the burst signal. See the timing diagram of Figures 25 and 27.

**Figure 38. Horizontal PLL (PLL1)**

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3) **Sandcastle Output** (Pin 35) – This is a multilevel output, at the horizontal frequency, used by the MC44140 delay line. See the timing diagram of Figures 25 and 27.
4) **16Fh/$C_{Sync}$** (Pin 13) – This is a dual purpose output, TTL levels, user selectable. When Bit $85–6 is set to 0, Pin 13 is a square wave at 16x the horizontal frequency (250 kHz for PAL, ≈ 252 kHz for NTSC). When Bit $85–6 is set to 1, Pin 13 is negative composite sync, derived from the internal sync separator. See the timing diagram of Figures 25 and 27.

The first three outputs mentioned above, and Pin 13 when set to 16Fh, are consistent, and do not change duty cycle or wave shape during the vertical sync interval. These four outputs will also be present regardless of the presence of a video signal at the selected input.

When Pin 13 is set to $C_{Sync}$ output, it follows the incoming composite sync format. If there is no video signal present at the selected input, this output will be a steady logic high.

Loading on these pins should not be less than 2.0 kΩ to either ground or 5.0 V.

Pin 11 is the filter for the PLL, and requires the components shown in Figure 38, and with the values shown in the application circuit of Figure 42. Pin 12 is a switch which allows the filtering characteristics at Pin 11 to be changed. Switching in the additional components (set $84–7 = 1) increases the filter time constant, permitting better performance in the presence of noisy signals.

The gain of the phase detector may be set high or low, depending on the jitter content of the incoming horizontal frequency, by using Bit $83–6. Broadcast signals usually have a very stable horizontal frequency, in which case the low gain setting ($83–6 = 0) should be used. When the video source is, for example, a VCR, the high gain setting may be preferable to minimize instability artifacts which may show up on the screen.

The gating function ($77–2) provides additional control where the stability of the incoming horizontal frequency is in question. With this bit set to 0, gating is in effect, causing the phase detector to not respond to the incoming sync pulses during the vertical interval. This reduces disturbances in this PLL due to the half–line pulses and their change in polarity. The gating may be disabled by setting this bit to 1 where the timing of the incoming sync is known to be stable. The gating cannot be enabled if the phase detector gain is set high ($83–6 = 1).

### Calibration Loop

The calibration loop (upper left portion of Figure 38) maintains a near correct frequency of this PLL in the absence of incoming sync signals. This feature minimizes re–adjustment and lock time when sync signals are re–applied. The calibration loop is similar to the PLL function, receiving one frequency from the crystal (either 4.43 MHz or 3.58 MHz) divided down to a frequency similar to the standard horizontal frequency. Bit $84–6 is used to set the frequency divider to the correct ratio, depending on which crystal is selected (see Table 9). The output of the frequency comparator operates an up/down counter, which in turn sets the D–to–A converter to drive the VCO through switch Sc. The resulting frequency at the output of the divide–by–64 block is then fed to the frequency comparator to complete the loop.

When a sync signal is not present at Phase Detector #1, and at the Coincidence Detector, as indicated by the coincidence detector's output (Flag 12), Bit $78–6 should be set to 0. This will cause the switch (Sc) to transfer to the D–to–A converter for two lines (lines 4, 5) in each vertical field, and will maintain the PLL1 at a frequency near the standard horizontal frequency (between 14 to 16 kHz). When lock to an incoming sync is established, Bit $78–6 may be set to 1, disabling the periodic recalibration function, or it may be left set to 0.

If a more accurate horizontal frequency is desired in the absence of an input signal, Bit $86–6. can be set to 1 (and Bit $84–6 set according to Table 9). This holds the horizontal frequency to ≈ 15.7 kHz. In this mode, Flag 12 will stay 0, as the PLL will not be able to lock–up to a newly applied external signal. To reset the system, set $86–6 to 0, write $00 to register $00, and then check Flag 12 to determine when the loop locks to an incoming signal.

**Table 9. Calibration Loop**

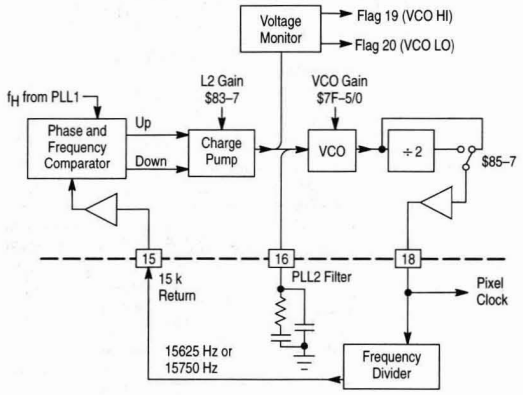
| Crystal | Set Bit $84–6 to |
|---|---|
| 14.3 MHz | 1 |
| 17.7 MHz | 0 |

On initial power up, Bit $86–6 (PLL1 EN) is automatically set to 1, engaging the calibration loop continuously. This condition will remain until this bit is set to 0, and $00 is written to register $00, as part of the initialization routine.

### Pixel Clock PLL (PLL2)

The second PLL, depicted in Figure 39, generates a high frequency clock which is phase–locked to the horizontal frequency.

**Figure 39. Pixel Clock PLL (PLL2)**



The phase and frequency comparator receive inputs from PLL1 ($f_H$, the horizontal frequency), and the frequency returned from the external divider. Any difference between these two signals causes the Up or Down output to change the charge pump's timing. The charge pump output is composed of two equal current sources which alternately source and sink current to the filter at Pin 16. The voltage at Pin 16 (which is the input to the VCO) is therefore determined by the relative timing of those two current sources, and the filter characteristics. A coarse control of the loop gain is set with Bit $83–7. Low gain is obtained by setting this bit to a 1, which sets the charge pump's output current sources to ≈ ±20 μA. Setting this bit to 0 sets the current sources to ≈ ±50 μA, or high gain.

Depending on the output frequency desired, and whether or not a 50–50 square wave is needed at the pixel clock, the ÷ 2 may be engaged (Bit $85–7). Generally, the ÷ 2 should not be engaged for high frequencies, and should be engaged for low frequencies, so as to keep the VCO's input voltage in a comfortable range (between 1.7 and 3.3 V). If the input voltage is outside this range, Flag 19 or 20 will switch high, indicating the need to fine tune the VCO's gain (control DAC $7F). The usable adjustment range for this DAC is 00 to ≈ 50. Settings of 51 to 62 will generally produce non–square wave outputs, and can be unstable. A setting of 63 will shut off the VCO, which should be done if the pixel clock is not used. When not used, Pin 18 will be at a constant low level.

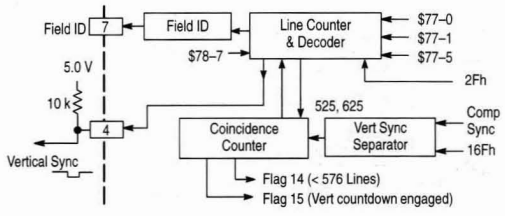
The pixel clock frequency is equal to the horizontal frequency ($f_H$) x the frequency divider ratio. The frequency divider can be made up of programmable counters (e.g., MC74F161A Applications Information), or it can be integrated into another device (e.g., an ASIC). The returned signal to Pin 15 must be TTL/CMOS logic levels, and must have a low time of > 200 ns. The phase comparator will phase–lock the falling edge of the returned signal with the rising edge of the $f_H$ signal at Pin 14 (see Figure 32).

### Vertical Decoder

The vertical decoder section, depicted in Figure 40, provides a vertical sync pulse and a field identification signal, as well as flags which indicate if vertical lockup has occurred, and if the number of horizontal lines per frame is greater or less than 576.

Inputs to this section consists of the composite sync from the sync separator, and horizontal related signals from the horizontal PLL (PLL1).

**Figure 40. Vertical Decoder**




The sync output (Pin 4) is an active low signal which starts after the horizontal half–line sync pulses change polarity (see Figures 33 and 34). The pulse width is nominally 500 μs for both PAL and NTSC signals. The position of this sync pulse's leading edge can be altered slightly with Bit $78–7, but this does not change the pulse width. Since the pulse width is generated digitally by counters, it will not vary with temperature, supply voltage, or manufacturing distribution. The sync output is an open–collector NPN output, requiring an external pull–up resistor. Minimum value for the pull–up is 1.0 kΩ, with 10 kΩ recommended for most applications.

Flag 14 (< 576 lines) is derived from the counter which compares the number of horizontal lines in each frame with a preset value of 576. This flag can be used externally to help determine whether PAL or NTSC signals are being provided to the MC44011. Flag 15 (Vertical countdown engaged) indicates that the vertical decoder has locked–up to the incoming composite sync information for eight consecutive fields (CB1, CA1 = 11).

The operation of the vertical decoder is controlled by Bits $77–0 and $77–1, according to Table 10.

**Table 10. Vertical Decoder Mode**

| CB1 ($77–1) | CA1 ($77–0) | Vertical Sync Mode |
|---|---|---|
| 0 | 0 | Force 625 |
| 1 | 0 | Force 525 |
| 0 | 1 | Injection Lock |
| 1 | 1 | Auto–Count |

The Injection Lock mode has a quicker response time, but less noise immunity, than the Auto–Count mode, and is normally used when attempting to lock–up to a new signal (such as when changing video input selection). Flag 15 will not switch high when in this mode. The Auto–Count mode, having a higher noise immunity, should be set once the horizontal PLL is locked–up (by reading Flag 12), and then Flag 15 should be checked after 8 fields for vertical lock–up.

The modes designated Force 525 and Force 625 can be used for those cases where it is desired to force the vertical sync pulse to occur twice every 525 or 625 lines, regardless of the incoming signal. In either of these modes, the MC44011's vertical section will not lock–up to the vertical sync information contained in the incoming composite video signal. If there is no incoming video signal, the vertical sync will still occur every 525 or 625 lines generated by the horizontal PLL. Flag 14 will indicate the number of lines selected, and Flag 15 will be a steady high.

Bit $77–5 (FSI) is used only in the PAL mode to select the vertical sync output rate. With this bit set to 0, the vertical sync pulses will be synchronized with the composite vertical sync input (every 20 ms). With this bit set to 1, the MC44011 will add a second vertical output sync pulse 10 ms after the one occurring at the vertical interval, giving a vertical sync rate of 100 Hz.

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The Field ID output (Pin 7) indicates which field is being processed when interlaced signals are applied, but the polarity depends on Bit $78–7. Table 11 indicates Pin 7 output. When non–interlaced signals are being processed, Pin 7 will be a constant high level when $78–7 is set to 1, and will be a constant low level when $78–7 is set to a 0. Loading on Pin 7 should not be less than 2.0 kΩ to either ground or 5.0 V. Figures 33 and 34 indicate the timing.

**Table 11. Field ID Output**

| 36/68 µs ($78–7) | Field | Field ID (Pin 7) |
|---|---|---|
| 1 | 1 | High |
| 1 | 2 | Low |
| 0 | 1 | Low |
| 0 | 2 | High |

### Sync Separator

The sync separator block provides composite sync information to the horizontal PLL, and to various other blocks within the MC44011 from one of several sources. It also provides composite sync output at Pin 13 when Bit $85–6 = 1. The sync source is selectable via the I²C bus according to Table 12.

**Table 12. Sync Source**

| $V_{in}$ Sync ($86–7) | Y2 Sync ($87–7) | RGB Sync ($88–6) | Sync Source |
|---|---|---|---|
| 0 | 0 | 0 | None |
| 0 | 0 | 1 | RGB (Pins 26–28) |
| 0 | 1 | 0 | Y2 (Pin 29) |
| 1 | X | X | Comp. Video (Pins 1, 3) |

Setting Bit $86–7 to a 1 overrides the other bits, thereby deriving the sync from the composite video input (either Pin 1 or 3) selected by Bit $88–7.

When RGB is selected, sync information on Pins 26 to 28 is used. Sync may be applied to all three inputs, or to any one with the other two ac grounded. If RGB signals are applied to these pins, sync may be present on any one or all three.

When Y2 is selected, sync information on Pin 29 is used. The sync amplitude applied to any of the above pins must be greater than 100 mV, and it must be capacitor coupled.

This system allows a certain amount of flexibility in using the MC44011, in that if the sync information is not present as part of the applied video signals, sync may be applied to another input. In other words, the input selected for the sync information need not be the same as the input selected for the video information.

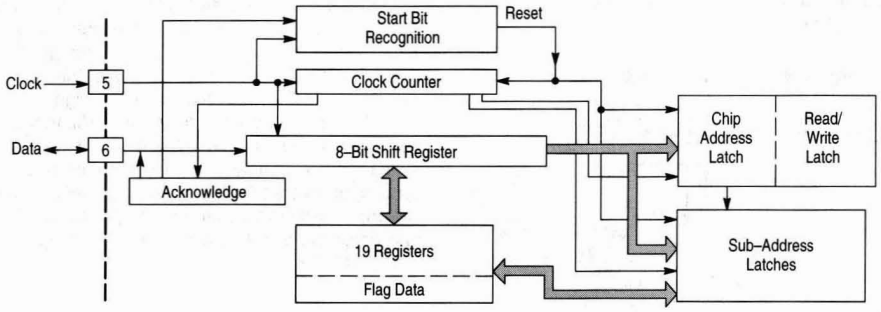
## SOFTWARE CONTROL OF THE MC44011

### I²C Interface

Communication to and from the MC44011 follows the I²C interface arrangement and protocol defined by Philips Corporation. In simple terms, I²C is a two line, multimaster bidirectional bus for data transfer. See Appendix C for a description of the I²C requirements and operation. Although an I²C system can be multimaster, the MC44011 never functions as a master.

The MC44011 has a write address of $8A, and a flag read address of $8B. It requires that an external microprocessor read the internal flags, and then set the appropriate registers. The MC44011 does not do any automatic internal switching when applied video signals are changed. A block diagram of the I²C interface is shown in Figure 41. Since writing to the MC44011's registers can momentarily create jitter and other undesirable artifacts on the screen, writing should be done only during vertical retrace (before line 20). Reading of flags, however, can be done anytime.

**Figure 41. I²C Bus Interface and Decoder**



**Write to Control Registers**

Writing should be done only during vertical retrace. A write cycle consists of three bytes (with three acknowledge bits):

1) The first byte is always the write address for the MC44011 ($8A).
2) The second byte defines the sub–address register (within the MC44011) to be operated on ($77 through $88, and $00).
3) The third byte is the data for that register.

Communication begins when a start bit (data taken low while clock is high), initiated by the master, is detected, generating an internal reset. The first byte is then entered, and if the address is correct ($8A), an acknowledge is generated by the MC44011, which tells the master to continue the communication. The second byte is then entered, followed by an acknowledge. The third byte is the operative data which is directed to the designated register, followed by a third acknowledge.

**Sub–Address Registers**

The sub–addresses of the 19 registers are at $77 through $88, and $00. Fourteen of the registers use Bits 0–5 to operate DACs which provide the analog adjustments. Most of the other bits are used to set/reset functions, and to select appropriate inputs/outputs. Table 13 indicates the assignments of the registers.

**Table 13. Sub–Address Register Assignments**

| Sub–Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| $77 | S–VHS Y | S–VHS C | FSI | $\overline{\text{L2 GATE}}$ | $\overline{\text{BLCP}}$ | $\overline{\text{L1 GATE}}$ | CBI | CAI |
| $78 | 36/38 µs | Cal Kill | (R–Y)/(B–Y) adjust DAC | | | | | |
| $79 | HI | VI | Subcarrier balance DAC | | | | | |
| $7A | Xtal | SSD | | | | | | |
| $7B | T1 | T2 | | | | | | |
| $7C | SSC | SSA | | | | | | |
| $7D | P1 | SSB | Blue bias for YUV operation DAC | | | | | |
| $7E | P3 | P2 | Red bias for YUV operation DAC | | | | | |
| $7F | D3 | D1 | Pixel Clock VCO Gain adjust DAC | | | | | |
| $80 | $\overline{\text{RGB EN}}$ | D2 | Blue Contrast trim DAC | | | | | |
| $81 | Y2 EN | Y1 EN | Main Contrast DAC | | | | | |
| $82 | YUV EN | YX EN | Red Contrast trim DAC | | | | | |
| $83 | L2 Gain | L1 Gain | Blue Brightness trim DAC | | | | | |
| $84 | H Switch | 525/625 | Main Brightness DAC | | | | | |
| $85 | PClk/2 | C Sync | Red Brightness trim DAC | | | | | |
| $86 | $V_{in}$ Sync | $\overline{\text{PLL1 En}}$ | Main Saturation DAC (Color Difference section ) | | | | | |
| $87 | Y2 Sync | 0 | (R–Y)/(B–Y) Saturation balance DAC (Decoder section) | | | | | |
| $88 | V2/V1 | RGB Sync | Hue DAC | | | | | |
| $00 | Set to $00 to start Horizontal Loop if $88–6 = 0 | | | | | | | |

Table 14 is a brief explanation of the individual control bits. A more detailed explanation of the functions is found in the block diagram description of the text (within the Functional Description section). Table 15 provides an explanation of the DACs. Each DAC is 6 bits wide, allowing 64 adjustment steps. The proper sequence and control of the bits and DACs, to achieve various system functions, is described in the Applications Information section.

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**Table 14. Control Bit Description**

| Control Bit | Name | Description |
|---|---|---|
| $77–7 | S–VHS–Y | Set to 0 for normal Composite Video inputs at V1 and/or V2 (Pins 1, 3). Set to 1 for S–VHS (YC) operation. When 1, the Y–input at the selected video input (V1 or V2, selected by Bit $88–7) bypasses the initial luma delay line, and associated luma/chroma filters and peaking. The signal passes through the second luma delay, adjustable with Bits D1–D3. Luma is output at Pin 33. |
| $77–6 | S–VHS–C | Set to 0 for normal Composite Video inputs at V1 and/or V2 (Pins 1, 3). Set to 1 for S–VHS (YC) operation. When 1, the chroma input at the non–selected video input (V1 or V2 by Bit $88–7) is directed to the ACC loop and PAL/NTSC detector. Color difference signals are then output at Pins 41 and 42. |
| $77–5 | FSI | Set to 0 for a Vertical Sync output rate of 50 Hz. Set to 1 for 100 Hz. Useable in PAL systems only. |
| $77–4 | $\overline{\text{L2 GATE}}$ | When set to 0, the pixel clock charge pump (PLL2) operation is inhibited during the Vertical Retrace to minimize momentary instabilities. When set to 1, PLL2 operation is not inhibited. |
| $77–3 | $\overline{\text{BLCP GATE}}$ | When 0, Vertical Gating of the black level clamp pulse during the Vertical Retrace occurs to minimize momentary instabilities. The Vertical Gating can be inhibited by setting this bit to 1. |
| $77–2 | $\overline{\text{L1 GATE}}$ | When set to 0, the horizontal PLL's phase detector (PLL1) operation is inhibited during the Vertical Retrace to minimize momentary instabilities. When set to 1, the phase detector is not inhibited. If PLL1 gain is high (Bit $83–6 = 1), gating cannot be enabled. |
| $77–1, 0 | CB1, CA1 | Sets the Vertical Timebase operating method according to Table 10. |
| $78–7 | 36/68 µs | When 0, the time delay from the sync polarity reversal within the Composite Sync to the leading edge of the Vertical Sync output (Pin 4) is 36 µs. When 1, the time delay is 68 µs. (See Figure 33 and 34). |
| $78–6 | CalKill | When 0, the Horizontal Calibration Loop is enabled for two lines (lines 4 and 5) in each field. When 1, the Calibration Loop is not engaged. Upon power–up, this bit is ineffective (Calibration Loop is enabled) until bit $86–6 is set to 0, and register $00 is set to $00. |
| $79–7 | HI | This bit is not used in the MC44011, and must be set to 1. |
| $79–6 | VI | This bit is not used in the MC44011, and must be set to 1. |
| $7A–7 | Xtal | When 0, the crystal at Pin 38 (17.7 MHz) is selected. When 1, the crystal at Pin 36 (14.3 MHz) is selected. |
| $7A–6 | SSD | This bit is not used in the MC44011, and must be set to 0. |
| $7B–7, 6 | T1, T2 | Used to set the Sound Trap Notch filter frequency according to Table 3. |
| $7C–7, 6 $7D–6 | SSC, SSA, SSB | Sets the NTSC/PAL decoder to the correct system according to Table 4. |
| $7D–7 $7E–7, 6 | P1, P2, P3 | Sets the Luma Peaking in the decoder section according to Table 5. (See text). |
| $7F–7, 6 $80–6 | D3, D1, D2 | Sets the Luma Delay in the decoder section according to Table 6. (See text). |
| $80–7 | $\overline{\text{RGB EN}}$ | When 0, permits the RGB inputs (Pins 26 to 28) to be selected with the Fast Commutate (FC) input (Pin 25). When 1, the FC input is disabled, preventing the RGB inputs from being selected. When the RGB inputs are selected, the Color Difference inputs (Pins 30, 31) are deselected. |
| $81–7 | Y2 EN | When 1, the Y2 Luma input (Pin 29) is selected. When 0, it is deselected. |
| $81–6 | Y1 EN | When 1, the Y1 Luma Signal (provided by the decoder section to the color difference section) is selected. When 0, it is deselected. |
| $82–7 | YUV EN | When 0, Pins 20 to 22 provide RGB output signals. When 1, those pins provide YUV output signals. |
| $82–6 | YX EN | Effective only when the RGB inputs are selected. When 0, the RGB inputs (Pins 26 to 28) are directed to the RGB outputs (Pins 20 to 22) via the Contrast and Brightness controls. When 1, the RGB inputs are directed through the Color Difference Matrix, allowing Saturation control in addition to the Brightness and Contrast controls. See Figure 36. |
| $83–7 | L2 Gain | When 0, the gain of the pixel clock VCO (PLL2) is high (50 µA). When 1, the gain is low (20 µA). |
| $83–6 | L1 Gain | When 0, the Horizontal Phase Detector Gain (PLL1) is low. When 1, the gain is high. |
| $84–7 | H Switch | When 0, Pin 12 is open. When 1, Pin 12 is internally switched to ground, allowing the PLL1 filter operation to be adjusted for noisy signals. |
| $85–7 | PClk/2 | When 0, the PLL2 VCO provides the Pixel Clock at Pin 18 directly. When 1, the VCO output is directed through a ÷ 2 stage, and then to Pin 18. |

**Table 14. Control Bit Description (continued)**

| Control Bit | Name | Description |
|---|---|---|
| $84–6 | 525/625 | This bit sets the division ratio from the crystal for the reference frequency for the Horizontal Calibration Loop. For NTSC systems, set to 1. For PAL systems, set to 0. |
| $85–6 | C Sync | When 0, Pin 13 will provide a square wave of ≈ 250 kHz (16 x Fh). When 1, Pin 13 provides a negative composite sync signal. See Figures 25, 27, 30, 31. |
| $86–7 | $V_{in}$ Sync | When 1, Composite Sync at the selected Video input (Pin 1 or 3) is used for all internal timing. When 0, the Sync source is selected by Bits $87–7 and $88–6. See Table 12. |
| $86–6 | PLL1 Enable | After power up, this bit must be set to 0, and then register $00 set to $00, to enable the Horizontal Loop (PLL1). Setting this bit to a 1 will disable the Horizontal Loop, and engages the Calibration Loop. |
| $87–7 | Y2 Sync | When 1, and $86–7 = $88–6 = 0, Composite Sync at the Y2 input (Pin 29) is used for all internal timing. When 0, the Sync source is selected by Bits $86–7 or $88–6. See Table 12. |
| $87–6 | 0 | This bit must always be set to 0. |
| $88–7 | V2/V1 | When Composite Video is applied, and this bit is 0, the Video 2 input (Pin 3) is directed to the Sound Trap. When 1, the Video 1 input (Pin 1) is selected. In S–VHS applications, when 0, Pin 3 is the Y (luma) input, and Pin 1 is the chroma input. When this bit is 1, Pin 1 is the luma input, and Pin 3 is the chroma input. |
| $88–6 | RGB Sync | When 1, and $86–7 = $87–7 = 0, Composite Sync at any or all of the RGB inputs (Pin 26 to 28) is used for all internal timing. When 0, the sync source is selected by Bits $86–7 or $87–7. See Table 12. |

**Table 15. Control DAC Description**

| Control Bits | Description |
|---|---|
| $78–5/0 | This DAC allows for a relative gain adjustment of the R–Y and B–Y outputs (Pins 41, 42) as a means of adjusting the color decoding accuracy. Nominal setting is 32. |
| $79–5/0 | Used to balance out reference errors of the color subcarrier, primarily for NTSC. Nominal setting is 32. Adjustment range is ≈ ±5°. |
| $7D–5/0 | Used to set the U (Pin 22) dc bias level. When in the YUV mode ($82–7 = 1), this setting should nominally be 32. When in RGB mode, set to 00. |
| $7E–5/0 | Used to set the V (Pin 22) dc bias level. When in the YUV mode ($82–7 = 1), this setting should nominally be 32. When in RGB mode, set to 00. |
| $7F–5/0 | Used to fine tune the gain of the Pixel Clock VCO to obtain optimum performance without instabilities. A setting of 63 will shut off the VCO. Setting 50 to 62 provide non–square wave outputs, and can be unstable. As the setting is increased from 00 to 49, the gain is increased. Changing this register does not change the Pixel Clock frequency. |
| $80–5/0 | Used to fine tune the contrast of the Blue output when in RGB mode. In YUV mode this provides a fine tuning of the color, similar to, but not to be confused with, hue. |
| $81–5/0 | Used to adjust the gain of the three outputs. In RGB mode this is the Contrast control. |
| $82–5/0 | Used to fine tune the contrast of the Red output when in RGB mode. In YUV mode this provides a fine tuning of the color, similar to, but not to be confused with, hue. |
| $83–5/0 | Used to fine tune the brightness of the Blue output when in RGB mode. In YUV mode this provides a fine tuning of the color, similar to, but not to be confused with, hue. |
| $84–5/0 | Used to adjust the brightness of the three RGB outputs. In YUV mode this DAC affects only Y output (Pin 21). |
| $85–5/0 | Used to fine tune the brightness of the Red output when in RGB mode. In YUV mode this provides a fine tuning of the color, similar to, but not to be confused with, hue. |
| $86–5/0 | Used to adjust the saturation of the RGB/YUV outputs of the Color Difference section. |
| $87–5/0 | Used to adjust the saturation of the R–Y, B–Y outputs (Pins 41, 42) of the Decoder section. |
| $88–5/0 | Used to adjust the hue of the R–Y, B–Y outputs (Pins 41, 42). Nominal setting is 32. |
| $00–7/0 | This register must be set to 00, after Bit $86–6 is set to 0, to enable the Horizontal Loop (PLL1) after power up, or anytime when Bit $86–6 is set to 0 after having been a 1. |

**NOTE:** The above DACs are 6–bits wide. The settings mentioned above, and in subsequent paragraphs are given in decimal values of 00 to 63. These are not hex values.

**Reading Flags**

A read cycle need not be restricted to the vertical interval, but may be done anytime. A flag read cycle consists of three bytes (with three acknowledge bits):

- The first byte is always the Read address for the MC44011 ($8B).
- The second and third bytes are the flag data.

Communication begins when a start bit (data taken low while clock is high), initiated by the master (not the MC44011), is detected, generating an internal reset. The first byte (address) is then entered, and if correct, an acknowledge is generated by the MC44011. The flag bits will then exit the MC44011 as two 8 bit bytes at clock cycles 10–17 and 19–26. The master (receiving the data) is expected to generate the acknowledge bits at clocks 18 and 27. The master must then generate the stop bit.

The MC44011 flags must be read on a regular basis to determine the status of the various circuit blocks. The MC44011 does not generate interrupts. It is recommended the flags be read once per field or frame. See Table 16 for a description of the flags.

**Table 16. Flag Description**

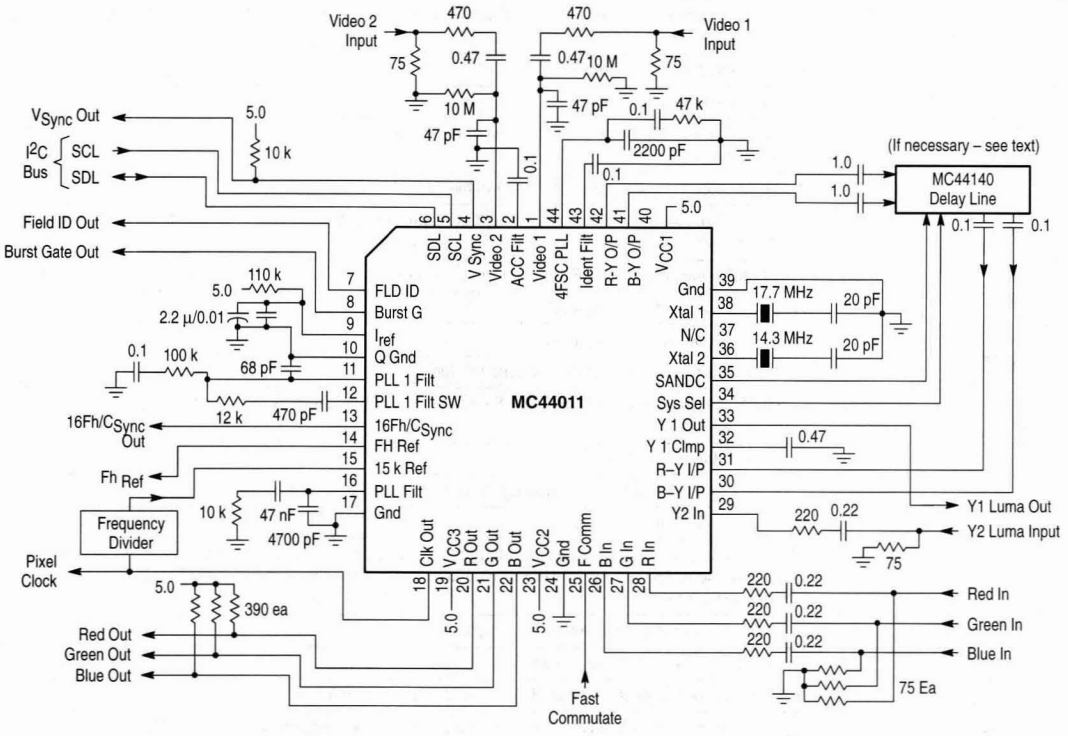
| Clock No. | Description (When Flag = 1) |
|---|---|
| 10 | Internally set to a Logic 1. |
| 11 | Horizontal Loop (PLL1) enabled, indicating the loop can be driven by the incoming sync. This bit will be low upon power up, and will change to a 1 after initialization of control Bit $86–6 and register $00. |
| 12 | Horizontal Loop (PLL1) not locked. Lack of incoming sync, or wrong sync source selection, or the wrong horizontal frequency, will cause the Coincidence Detector to indicate a "not locked" condition. |
| 13 | Internally set to Logic 0. |
| 14 | Less than 576 horizontal lines counted per frame. This flag helps determine the applied video system. When high, a 525 line system (NTSC) is indicated. When low, a 625 line system (PAL) is indicated. |
| 15 | Vertical Countdown engaged. When high, this flag indicates the Vertical Countdown section has successfully maintained lock for 8 consecutive fields, indicating therefor a successful vertical lock–up. This flag is low in the Injection Lock mode. |
| 16 | Internally set to a Logic 1. |
| 17 | Internally set to a Logic 1. |
| 18 | (Acknowledge pulse). |
| 19 | Pixel clock VCO control voltage too low (< 1.7 V at Pin 16). This indicates the VCO may not function correctly as the control voltage is near one end of its range. The DAC setting at register $7F–5/0 must be increased, and/or the ÷ 2 block must be selected (set $85–7 = 1), to clear this flag. |
| 20 | Pixel clock VCO control voltage too high (> 3.3 V at Pin 16). This indicates the VCO may not function correctly as the control voltage is near one end of its range. The DAC setting at register $7F–5/0 must be reduced, and/or the ÷ 2 block must be deselected (set $85–7 = 0) to clear this flag. This flag will be high if the VCO is off (DAC $7F = 63). |
| 21 | Internally set to a Logic 1. |
| 22 | Internally set to a Logic 0. |
| 23 | ACC Loop is active, indicating it is locked up to the color burst signal. The Color Burst amplitude must exceed 30 mVpp, and the correct crystal selected, for lock–up to occur. |
| 24 | PAL system identified by the decoder, indicating the decoder recognizes the line–by–line change in the burst phase. When NTSC is applied, this flag is 0. |
| 25 | Not used. |
| 26 | Internally set to a Logic 0. |
| 27 | (Acknowledge pulse). |

## APPLICATIONS INFORMATION

### Design Procedure and PC Board Layout

The external components required by the MC44011 are shown in Figure 42. Except for the crystals, all the components are standard value resistors and capacitors, and can be non–precision. Table 18 describes the external components for each pin.

**Figure 42. Basic Functional Circuit**




### Crystal Specifications and Operation

The crystals used with the MC44011 should comply with Table 17 specifications.

**Table 17. Crystal Specifications**

| | |
|---|---|
| Frequency: (4 x Subcarrier) | NTSC (14.31818 MHz)<br>PAL (17.734472 MHz)<br>PAL–M (14.30244 MHz) |
| Pull–in range: | ±1600 Hz<br>(with respect to crystal frequency) |
| Tolerance: | 30 ppm (with fixed load capacitor) |
| Temperature Coefficient: | 50 ppm (with fixed load capacitor) |
| Operating Mode: | Fundamental series resonance |
| Load Capacitance: | Nominally 20 pF |
| Motional Capacitance: | 10 to 30 fF |
| Series Resistance: | < 30 Ω (nominally 10 Ω) |

The oscillator output resistance at Pin 36 is nominally 300 Ω for NTSC mode, and 400 Ω at Pin 38 for PAL mode. It is recommended that a stray capacitance (PC board, package pins, etc.) of 4.0 to 5.0 pF be included when selecting a crystal.

The above values for tolerance and temperature coefficent can be increased if a trimmer capacitor is used for the load capacitor.

The crystal PLL filter (Pin 44) voltage is between 1.8 and 3.8 V in normal operation. If the color output of the MC44011 is incorrect, or non–existent (ACC flag off), this voltage should be checked. If it is beyond either of the above limits, the capacitor in series with the crystal should be changed so as to allow the PLL to pull–in the crystal. The capacitor is generally specified by the crystal manufacturer, but should also comply with Table 17 specifications. If no burst is present, Pin 44 voltage will be ≈ 1.3 V.

The selected crystal frequency can be checked by using a scope at the non–selected crystal pin. The signal amplitude is nominally 200 to 400 mVpp. In this way the selected crystal's frequency is not affected by the scope probe.

**Table 18. External Components**

| Pin | Name | Function |
|---|---|---|
| 1, 3 | Video 1, Video 2 | Input signals must be capacitor–coupled. The 470 Ω resistors protect the pins from ESD and RFI. The 75 Ω resistors are not required by the MC44011, but depend on the signal source. The 47 pF capacitors filter high frequency noise. |
| 2 | ACC Filter | The 0.1 μF ceramic capacitor filters the Automatic Gain circuit. |
| 4 | Vert Sync | The pull–up resistor is required for this open–collector output. |
| 5, 6 | SCL, SDL | Pull–up resistors are required on each $I^2C$ line since outputs are open–collector. They are typically located at the master device. |
| 7 | Field ID | No external components required. |
| 8 | Burst Gate | No external components required. |
| 9 | $I_{ref}$ | The 110 kΩ resistor provides ≈ 32 μA from the 5.0 V source. This pin must be well filtered to the Quiet Ground (Pin 10). |
| 10 | Quiet Gnd | This is the Reference Ground for Pin 9 and the PLL1 Filter. |
| 11 | PLL1 Filter | The 100 kΩ resistor, and the 0.1 μF and 68 pF capacitors are the filter network for this PLL. Connect to Pin 10 ground. |
| 12 | PLL1 Filt SW | The 12 kΩ resistor and 470 pF capacitor give the filter a longer time constant when Pin 12 is switched in. |
| 13 | $16Fh/C_{Sync}$ | No external components required. |
| 14 | Fh Ref | No external components required. |
| 15 | 15 k Return | TTL Return signal from external frequency divider. |
| 16 | PLL2 Filter | The 10 kΩ resistor and 47 nF and 4.7 nF capacitors are the filter network for this PLL. Connect to Pin 17 ground. |
| 17 | Ground | Ground for the Pixel Clock circuit. |
| 18 | Clk Out | Pixel Clock output to external frequency divider and triple A/D converter. |
| 19 | $V_{CC3}$ | 5.0 V supply for the Pixel Clock circuit. |
| 20, 21, 22 | R, G, B Out | The 390 Ω pull–up resistors are required for these open–collector outputs. The pull–ups should go to a clean, well filtered 5.0 V supply. These pins cannot drive 75 Ω directly. If required to do so, see text for suggested buffer. |
| 23 | $V_{CC2}$ | 5.0 V supply for the Color Difference section. |
| 24 | Ground | Ground for the Color Difference section. |
| 25 | Fast Comm | No external components required. This input *should not* be left open. |
| 26, 27, 28 | B, G, R In | Input signals must be capacitor–coupled. The 220 Ω resistors protect the pins from ESD and RFI. |
| 29 | Y2 Input | Input signals must be capacitor–coupled. The 220 Ω resistor protects the pin from ESD and RFI. The 75 Ω resistor is not required by the MC44011, but depends on the signal source. |
| 30, 31 | B–Y, R–Y In | Input signals must be capacitor–coupled. The MC44140 is required if PAL signals are processed (see text). |
| 32 | Y1 Clamp | The 0.1 μF ceramic capacitor provides clamping for the Y1 output. |
| 33 | Y1 Out | No external components required. This pin cannot drive 75 Ω directly. If required to do so, see text for suggested buffer. |
| 34, 35 | System Sel, Sandcastle | For use by the MC44140 delay line. No other external components required. |
| 36, 38 | Xtal 2, Xtal 1 | A 17.7 MHz crystal is required (at Pin 38) for PAL signals, and a 14.3 MHz crystal is required (at Pin 36) for NTSC signals. If only one crystal is required, leave the other pin open. The series capacitor depends on the crystal manufacturer. (See Table 17 for crystal specs.) |
| 37 | N/C | No external components required. |
| 39 | Ground | Ground for Color Decoder section. |
| 40 | $V_{CC1}$ | 5.0 V supply for the Color Decoder section. |
| 41, 42 | B–Y, R–Y Out | The MC44140 is required if PAL signals are processed. Otherwise, capacitor–couple to Pins 30, 31 (see text). |
| 43 | Indent Filter | The 0.1 μF ceramic capacitor provides filtering for the Identification circuit. |
| 44 | 4FSC PLL | The 47 kΩ resistor, and 0.1 μF and 2.2 nF capacitors are the filter network for the crystal PLL. Connect to Pin 39 ground. |

### Power Supplies and Ground

There are three $V_{CC}$ pins (Pins 19, 23, and 40) which must be connected to a source of 5.0 V, ±5%. Since the three pins are internally connected by diodes, none can be left open, even if a particular section (such as the Pixel Clock Generator) is to be unused. Total current required is ≈ 135 mA (including the RGB output load current). There are four ground pins (Pins 10, 17, 24, and 39) which must be connected together, and preferably connected to a ground plane.

Pins 19 and 17 are the $V_{CC}$ and ground for the Pixel Clock Generator, and the circuitry associated with the Pixel Clock should be referenced to those two pins.

Pins 23 and 24 are the $V_{CC}$ and ground for the Color Difference section, which includes the RGB outputs. The output pull–up resistors should be connected to the $V_{CC}$ at Pin 23.

Pins 40 and 39 are the $V_{CC}$ and ground for the Color Decoder, Sync Separator, Horizontal PLL and the Vertical Decoder. Pin 10 is the Quiet Ground for the horizontal PLL's VCO and filter, and therefore, the components on Pins 9 and 11 should be connected as close as possible to Pin 10.

Bypassing of the power supplies must be done as close as possible to each $V_{CC}$ pin, and at the output pull–up resistors. Recommended bypassing components are a 10 µF tantalum capacitor in parallel with a 0.01 µF ceramic.

### Input Signals

The various video inputs, Video 1 and 2, Red In, Green In, Blue In, R–Y, B–Y, and Y2 inputs, are designed to accept standard level analog video waveforms. They are not designed for digital signals. The input impedance of the above pins is high. The need for 75 Ω terminations for those video signals depends on the video source itself. All of the above signals must be capacitor–coupled as clamping is provided internally.

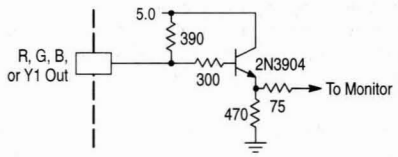
The $I^2C$ inputs (SCL, SDL) are designed according to the $I^2C$ specifications, which define $V_{OL}$ as between 0 and 1.5 V, and $V_{OH}$ as between 3.0 V to $V_{CC}$. See Appendix C.

The 15 k Return and Fast Commutate (Pins 15 and 25, respectively) are designed for TTL level signals. If unused, they should not be left open, but connected to 5.0 V, or ground, as appropriate.

### Output Signals

The RGB/YUV outputs are open–collector, and require pull–up resistors (typically 390 Ω) to a clean 5.0 V ($V_{CC2}$). The output impedance is such that the load impedance (to ground) should be >1.5 kΩ. If it is desired to drive a 75 Ω load (e.g., a monitor) from these outputs, a simple buffer (see Figure 43) can be added.

**Figure 43. Output Buffer**




The Y1 output (Pin 33) has an output impedance of ≈ 300 Ω, and can be used as a monitoring point, or to drive the input of the MC44145 sync separator, or other high impedance loads (minimum load for Y1 is 1.0 kΩ). If it is to be used to drive a 75 Ω load, the buffer shown in Figure 43 can be used, *except the 390 Ω resistor must be deleted.*

The Vertical Sync output (Pin 4) is an open–collector logic level output, and requires a pull–up resistor to 5.0 V. 10 kΩ is recommended, but it can be as low as 1.0 kΩ. The $I^2C$ data line (SDL, Pin 6) is also open–collector when it is an output, and can sink a maximum of 3.0 mA. Only one pull–up resistor is required on the SDL line (regardless of the number of devices on that line), and it is typically near the master device. The Field ID, Burst Gate, 16Fh/$C_{Sync}$, Fh Ref, and Pixel Clock outputs are logic level totem–pole outputs.

### PC Board

The PC board layout should be neat and compact, and should preferably have a ground plane. If feasible, a second plane should be provided for the 5.0 V supply, but this is not mandatory. The components at Pins 9 and 11 should be connected to the same ground track which goes to Pin 10. The $V_{CC}$ and ground should be connected as directly as possible to the power supply, and not routed through a maze of digital circuitry before arriving at the MC44011. Since the MC44011 is intended to be used with A/D converters and high speed digital signals, it is expected digital circuitry will be on the same board. Care should be taken in the layout to prevent digital noise from entering the analog portions of the MC44011. The most sensitive pins are Pins 1, 2, 3, 9, 10, 11, 12, 16, and 44, and should be protected from noise.

### Initialization and Programming Information

Upon powering up the MC44011, initialization consists of first filling the registers with initial values to set a known condition. Table 19 provides recommended values for the initial settings, although these may be tailored for each application (with the exception of Bits $79–6,7, $7A–6, $86–6, and $87–6). Table 19 settings will set up the MC44011 to the following conditions:

- Composite video input at Video 1 (Pin 1), NTSC, using the crystal at Xtal 2 (Pin 36).
- Y1 enabled, RGB outputs enabled, and Composite Sync at Pin 13
- RGB inputs not enabled (R–Y, B–Y inputs are enabled)
- The Sound Trap at 4.5 MHz
- The Luma Peaking at 0 dB
- The Luma Delay at minimum
- High gain and high noise rejection for the horizontal PLL
- Vertical decoder set to Injection Lock mode
- The Pixel Clock VCO is off

After the registers are initialized, then set Bit $86–6 to 0, and load register $00 with $00. This will enable the horizontal PLL, permitting normal operation.

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**Table 19. Recommended Initial Settings**

| Sub–Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| $77 | S–VHS Y = 0 | S–VHS C = 0 | FSI = 0 | $\overline{\text{L2 Gain}}$ = 0 | $\overline{\text{BLCP}}$ = 0 | $\overline{\text{L1 Gain}}$ = 0 | CBI = 0 | CAI = 1 |
| $78 | 36/68 µs = 0 | Calkill = 0 | (R–Y)/(B–Y) Adjust DAC = 32 | | | | | |
| $79 | HI = 1 | VI = 1 | Subcarrier Balance DAC = 32 | | | | | |
| $7A | Xtal = 1 | SSD = 0 | – | | | | | |
| $7B | T1 = 1 | T2 = 1 | – | | | | | |
| $7C | SSC = 0 | SSA = 1 | – | | | | | |
| $7D | P1 = 1 | SSB = 0 | Blue Bias = 00 | | | | | |
| $7E | P3 = 1 | P2 = 1 | Red Bias = 00 | | | | | |
| $7F | D3 = 0 | D1 = 0 | Pixel Clock VCO Gain Adjust = 63 | | | | | |
| $80 | $\overline{\text{RGB EN}}$ = 1 | D2 = 0 | Blue Contrast Trim = 32 | | | | | |
| $81 | Y2 EN = 0 | Y1 EN = 1 | Main Contrast = 47 | | | | | |
| $82 | YUV EN = 0 | YX EN = 0 | Red Contrast Trim = 32 | | | | | |
| $83 | L2 Gain = 1 | L1 Gain = 1 | Blue Brightness Trim = 32 | | | | | |
| $84 | H Switch = 1 | 525/625 = 1 | Main Brightness = 30 | | | | | |
| $85 | PClk/2 = 1 | $C_{Sync}$ = 1 | Red Brightness Trim = 32 | | | | | |
| $86 | $V_{in}$ Sync = 1 | $\overline{\text{PLL1 EN}}$ = 1 | Main Saturation (Color Difference section ) = 32 | | | | | |
| $87 | Y2 Sync = 0 | 0 | (R–Y)/(B–Y) Saturation Balance (Decoder section) = 15 | | | | | |
| $88 | V2/V1 = 1 | $RGB_{Sync}$ = 0 | Hue = 32 | | | | | |

**NOTE:** These settings are for power–up initialization only. Refer to the text, and Appendix B, for subsequent modifications based on the application.

Then, after selecting the desired input(s) (from Pins 1, 3, or 26 to 31), and based on the applied signals at those inputs, and by reading the flags, the registers are adjusted for the desired and proper mode of operation. A suggested routine for setting modes is given in Appendix B. The "initial values" in the Control DACs table of Appendix B are those in Table 19. The remainder of the flow chart is a recommendation only, and should be tailored for each application.

The monitoring of flags should be done on a regular basis, and it is recommended it be done once per field. See Table 16 (in the Functional Description section) for a summary of the flags. Should any flags change, the following procedures are recommended:

**Flag 11 (Horizontal Enabled)** – Once enabled by setting Bit $86–6 = 0, this flag should always remain a 1. Should it change to 0, reset $86–6 to 0, and write $00 to register $00 again. If the flag does not return to a 1, this indicates a possible device malfunction.

**Flag 12 (Horizontal Out–of–Lock)** – When 1, this indicates:

a. the wrong input is selected (Bits $88–7, $81–7, $80–7, and $77–7,6), or;
b. the wrong sync source is selected (Bits $86–7, $87–7, and $88–6), or;
c. the incoming signal is somewhat unstable, as from a VCR tape (change Bit $83–6), and/or;
d. the incoming signal is noisy (change Bit $84–7), or;
e. a loss of the incoming signal with sync.

(It is possible for this flag to flicker when the video signal is from a poor quality tape, or other poor quality source.)

**Flag 14 (Less than 576 lines)** – This flag, from the vertical decoder, is used to help determine if the signal is PAL or NTSC. Should it change, this indicates the incoming signal has changed format, or possibly one of the items listed under Flag 12 above.

**Flag 15 (Vertical Countdown Engaged)** – Bits 77–0 and 1 must be set to 1 (after Flag 12 reads 0) for this flag to indicate correctly. Then this flag will change to a 1 after 8 fields of successful synchronization of the internal counters with the incoming signal. To change to a 0 requires 8 consecutive fields of non–synchronization. If this flag changes to 0, this indicates a loss of signal, a change of signal format, or instability in the horizontal PLL.

**Flags 19, 20 (VCO Control Voltage Low/High)** – These flags are meaningful only if the Pixel Clock Generator is used. If Flag 19 is a 1, the gain of the pixel clock VCO needs to be increased by increasing the value of register $7F, and/or set Bit $85–7 = 1. If Flag 20 is a 1, the value of the register must be decreased, and/or set Bit $85–7 = 0. If the VCO is turned off ($7F = 63), Flag 19 will be 0, and Flag 20 will be 1.

**Flag 23 (ACC Active)** – If this flag is a 0, it indicates the ACC loop is not active. This will happen if the burst signal is less than 30 mVpp, if the incorrect crystal is selected ($7A–7), if the crystal PLL is not locked, or if the horizontal PLL is not locked.

**Flag 24 (PAL Identified)** – This flag is a 1 when PAL signals are applied, and a 0 when NTSC signals are applied, or when no burst is present.

It is recommended that the Color Decoder section, and crystal, should be set according to the state of Flags 14, 23, and 24 according to Table 20.

**Table 20. Color Standard Selection Table**

| Flags | | | Bit Settings | | | | |
|---|---|---|---|---|---|---|---|
| #14 <576 Lines | #23 ACC Active | #24 PAL Signal | Crystal | SSA ($7C–6) | SSB ($7D–6) | SSC ($7C–7) | System |
| X | 0 | X | Either | 1 | 1 | 0 | Color Kill |
| 0 | 1 | 0 | Either | 1 | 1 | 0 | Color Kill |
| 0 | 1 | 1 | 17.7 MHz | 0 | 1 | 0 | PAL |
| 1 | 1 | 0 | 14.3 MHz | 1 | 0 | 0 | NTSC |
| 1 | 1 | 1 | (Note 1) | 0 | 1 | 0 | PAL–M |

**NOTES:** 1. PAL–M, used in Brazil and other South American countries, can be decoded by the MC44011, but requires a 14.3024 MHz crystal.
2. SSD ($7A–6) is always set to 0.

## MISCELLANEOUS APPLICATIONS INFORMATION

### Use of the MC44140 Delay Line

The MC44140 delay line is generally required if PAL signals are to be decoded, so as to average out the line–by–line color information associated with PAL color decoding. If the same single PAL video source is always used in a particular application, the delay line can be eliminated, and any slight phase errors can be corrected with the DAC of register $79–5/0. If, however, various video sources can be used, and/or if the video signal is less than broadcast quality, it is recommended the MC44140 delay line be included.

The MC44140 acts on the color difference signals before they enter the color difference stage of the MC44011. It will, however, pass NTSC signals through without modifications. The MC44011 uses the System Select output (Pin 34) to indicate to the delay line which signals are being processed. The System Select voltage is set when the color decoder is set with Bits SSA, SSB, SSC, SSD. The Sandcastle output (Pin 35) provides the horizontal timing signals to the delay line. In addition, the MC44140 uses the crystal frequency for the internal counters.

The MC44140 is inserted into the circuit between the Color Difference outputs and inputs of the MC44011. In addition, the MC44140 provides pins (Pins 8,9) for inserting an alternate source of color difference signals to the MC44011 by setting the System Select to external (Bit $7C–7 = 1). See Figure 44 for a suggested circuit.

If only NTSC signals are to be processed by the MC44011, the MC44140 is not needed. In this case, connect Pin 42 to Pin 31 with a 0.1 µF capacitor, and similarly connect Pin 41 to Pin 30.

**Figure 44. Incorporating the MC44140 Delay Line**

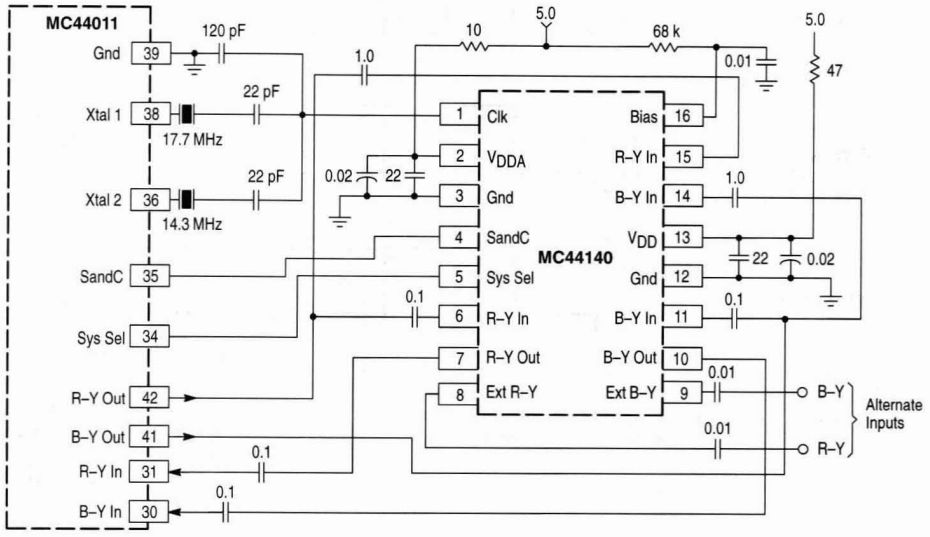
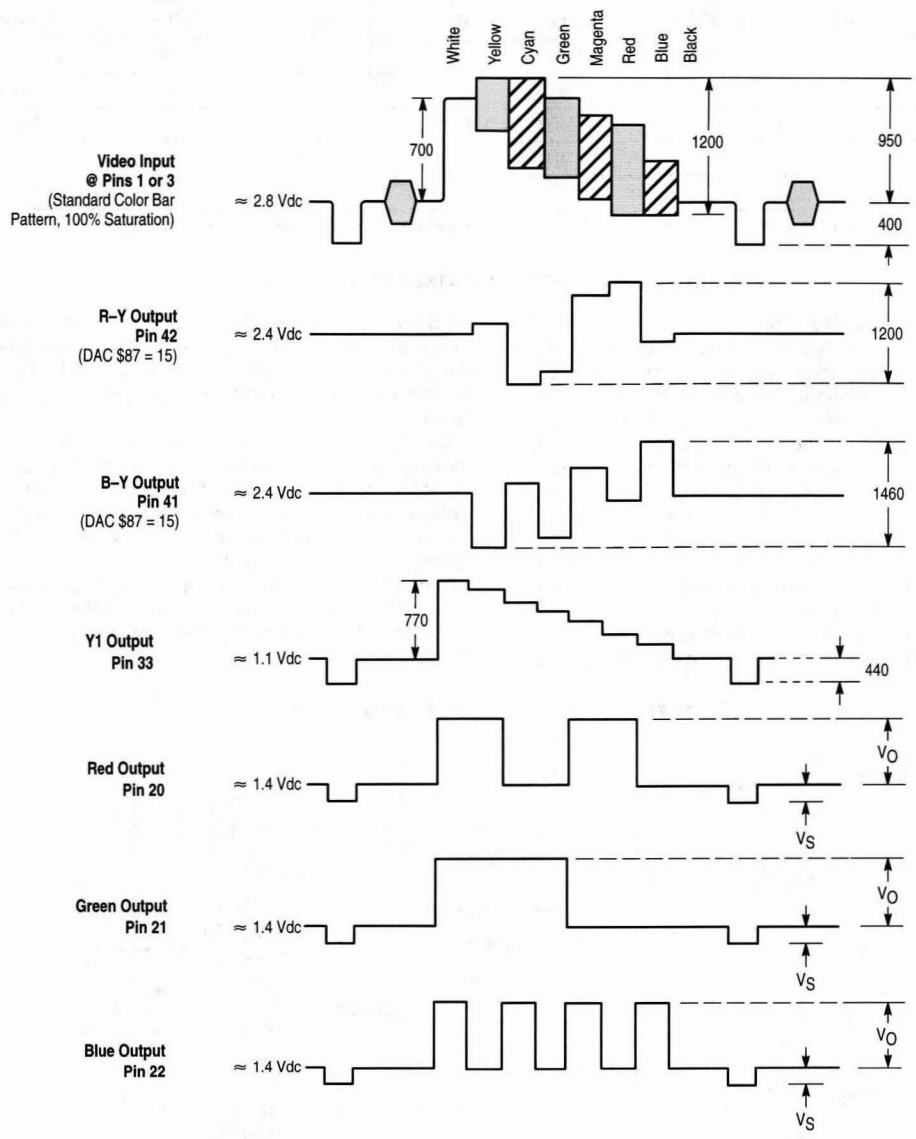


**Figure 45. Typical Waveforms**




DACs set per Table 19. All amplitudes in milliVolts.
Voltages are nominal, and do not represent guaranteed limits.

| DAC 81 | $V_O$ | $V_S$ |
|---|---|---|
| 32 | 1725 | 220 |
| 47 | 2360 | 340 |
| 63 | 3160 | 440 |

### Use of the MC44145 Pixel Clock Generator

For most applications the Pixel Clock Generator (PLL2) within the MC44011 will be suitable. In those cases, however, where the pixel clock frequency is set to within ±1.0 MHz of the selected crystal frequency (14.3 MHz or 17.7 MHz), or to within ±1.0 MHz of double the selected crystal frequencies, undesirable noise artifacts may be present on the RGB outputs. In these cases the MC44145 should be used to generate the Pixel Clock. The circuitry within the MC44145 duplicates that of the MC44011, but since it is physically removed from the circuitry within the MC44011, the interfering noise is not generated. If the MC44145 is used, the Pixel Clock Generator within the MC44011 should be shut off by setting the DAC of register $7F to 63, eliminating the components at Pin 16, and grounding Pin 16.

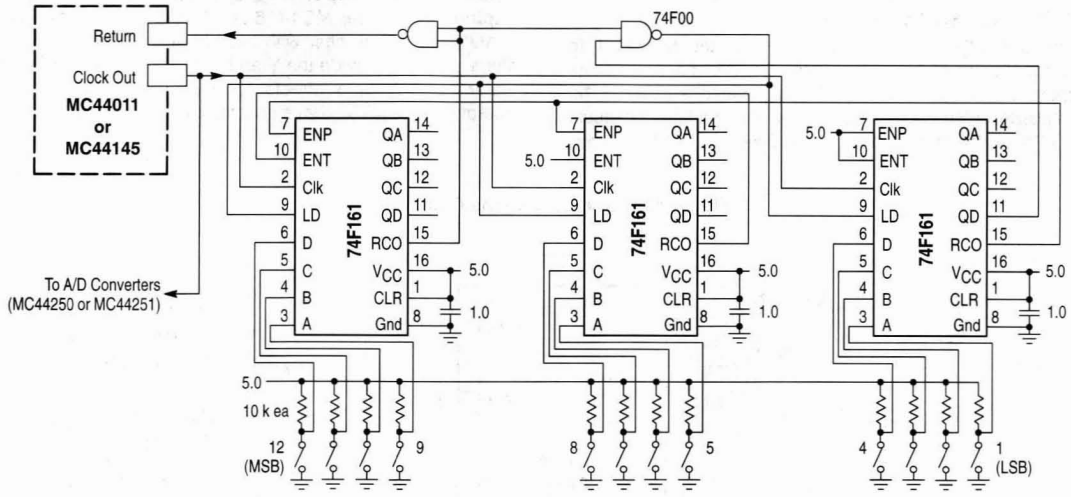
If the desired pixel clock frequency is close to the limits mentioned above, then experimentation may be used to determine the need for the MC44145.

### Frequency Divider

The frequency of the Pixel Clock is determined by the horizontal frequency and an external frequency divider. The divider simply divides down the Pixel Clock Frequency so that it equals the horizontal frequency. The PLL within the MC44011 (or the MC44145) compares the horizontal frequency with the returned frequency, and adjusts the internal VCO accordingly, to achieve the proper relationship between the two. The PLL will phase–lock the negative–going edge of the returned signal with the positive–going edge of the Fh signal (Pin 14 of the MC44011). The returned signal must be TTL logic level amplitudes, and have a minimum low time of 200 ns. A suggested circuit for the divider, shown in Figure 46, uses 74F161 programmable binary counters. The 12 switches at the bottom are used to set the division ratio, and hence the Pixel Clock frequency.

The division ratio is determined by dividing the desired clock frequency by the horizontal frequency, and then using the closest whole number. After determining the binary equivalent of that number, close each switch corresponding to a 1, and leave open each switch corresponding to a 0. Alternately, the switches could be deleted, and Pins 3, 4, 5 and 6 of each 74F161 hard–wired to 5.0 V or ground, or controlled by a microprocessor where different pixel clock frequencies are required.

**Figure 46. Suggested Frequency Divider**

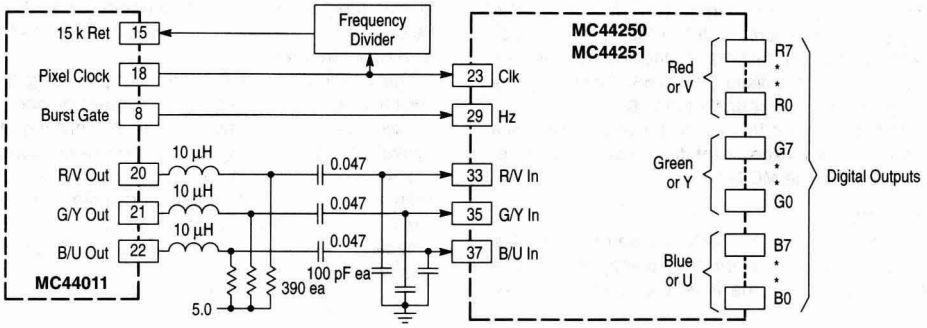


### Connecting the MC44011 to the MC44250 or MC44251 A/D Converter

The MC44250 and MC44251 triple A/D converters are designed to accept RGB or YUV inputs, and provide 8–bit equivalents of each. Additionally, the inputs have black level clamps, allowing the input signals to be capacitor–coupled.

The simplified schematic of Figure 47 shows the connections between the MC44011 and the MC44250/1, including anti–aliasing filters between the devices. Connection to other A/D converters would be done in a similar manner. Refer to the appropriate data sheet for details.

**Figure 47. Connecting to a Triple A/D Converter**

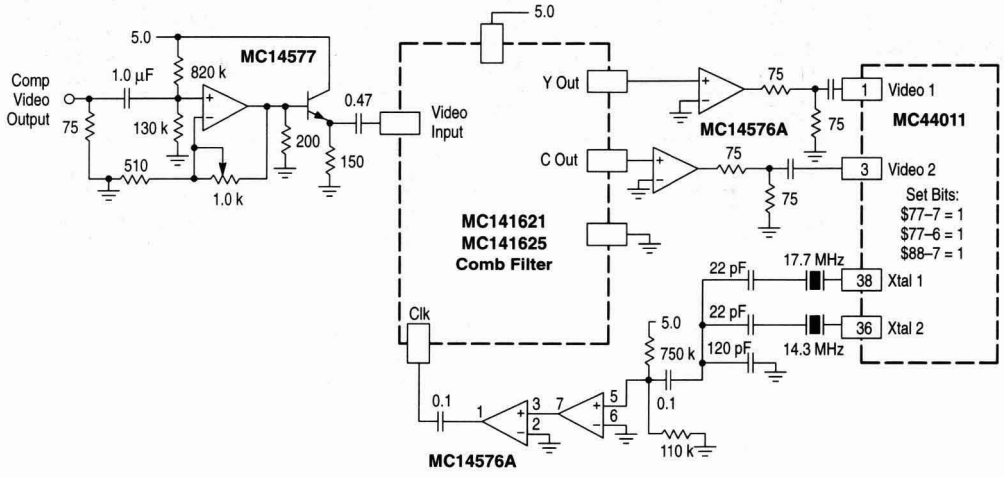



### Connecting the MC44011 to the MC141621 or MC141625 NTSC Comb Filter

A comb filter can be used ahead of the MC44011 to enhance picture quality by providing a more accurate separation of the luma and chroma components from the composite video, without sacrificing bandwidth. The usual benefits are reduced dot crawl, and increased color purity.

Figure 48 (a simplified schematic) shows the normal mode of implementing the MC141621 (NTSC) or MC141625 (PAL/NTSC) comb filter with the MC44011. The two comb filters can also provide the Y and C signals in digital format. Refer to their data sheets for details. The MC14576A operational amplifiers have an internally set gain of 2.

**Figure 48. Implementing the Comb Filter**



## APPENDIX A

### Control Bit Summary

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| $77 | S–VHS Y | S–VHS C | FSI | L2 Gate | BLCP | L1 Gate | CBI | CAI |
| | 0 = Comp. Video<br>1 = S–VHS | | 0 = 50 Hz<br>1 = 100 Hz | 0 = PLL2 Gating | 0 = Clamp Gating | 0 = PLL1 Gating | | |
| $78 | 36/68 | CalKill | Vertical Time Constant<br>1 = Cal Loop Disabled | | | | | |
| $79 | HI | V1 | Set to 1, 1 | | | | | |
| $7A | Xtal | SSD | Set to 0<br>1 = Pin 36 Crystal | | | | | |
| $7B | T1 | T2 | | | | | | |
| $7C | SSC | SSA | | | | | | |
| $7D | P1 | SSB | | | | | | |
| $7E | P3 | P2 | | | | | | |
| $7F | D3 | D1 | | | | | | |
| $80 | RGB EN | D2 | 0 = RGB Inputs Enabled | | | | | |
| $81 | Y2 EN | Y1 EN | 1 = Y1 Enabled<br>1 = Y2 Enabled | | | | | |
| $82 | YUV EN | YX EN | 1 = RGB Matrix Enabled<br>1 = YUV Outputs | | | | | |
| $83 | L2 Gain | L1 Gain | 1 = PLL1 Gain High<br>1 = PLL2 Gain Low | | | | | |
| $84 | H Switch | 525/625 | 1 = NTSC<br>1 = Switch Closed | | | | | |
| $85 | PClk/2 | C Sync | 1 = Comp Sync<br>1 = ÷ 2 Enabled | | | | | |
| $86 | $V_{in}$ Sync | PLL1 EN | 0 = PLL1 Enabled<br>1 = Comp Video Sync Source | | | | | |
| $87 | Y2 Sync | 0 | Set to 0<br>1 = Y2 Sync Source | | | | | |
| $88 | V2/V1 | RGB Sync | 1 = RGB Sync Source<br>1 = Pin 1 Input | | | | | |

| CBI | CAI | Sync Mode |
|---|---|---|
| 0 | 0 | Force 625 |
| 1 | 0 | Force 525 |
| 0 | 1 | Inj Lock |
| 1 | 1 | Auto Count |

| Sound Trap Notch Frequency | | | |
|---|---|---|---|
| T1 | T2 | PAL | NTSC |
| 0 | 0 | 6.5 MHz | 5.25 MHz |
| 0 | 1 | 5.5 + 5.75 MHz | 4.44 + 4.64 MHz |
| 1 | 0 | 6.0 MHz | 4.84 MHz |
| 1 | 1 | 5.5 MHz | 4.44 MHz |

| SSA | SSB | SSC | Color System |
|---|---|---|---|
| 0 | 0 | 0 | Not Used |
| 0 | 1 | 0 | PAL |
| 1 | 0 | 0 | NTSC |
| 1 | 1 | 0 | Color Kill |
| X | X | 1 | External |

| P1 | P2 | P3 | Y1 Peak |
|---|---|---|---|
| 0 | 0 | 0 | 9.5 dB |
| 0 | 0 | 1 | 8.5 |
| 1 | 0 | 0 | 7.7 |
| 1 | 0 | 1 | 6.5 |
| 0 | 1 | 0 | 5.3 |
| 0 | 1 | 1 | 3.8 |
| 1 | 1 | 0 | 2.2 |
| 1 | 1 | 1 | 0 |

| | | | Luma Delay | |
|---|---|---|---|---|
| D1 | D2 | D3 | 14.3 MHz | 17.7 MHz |
| 0 | 0 | 0 | 690 ns | 594 ns |
| 0 | 0 | 1 | 760 | 650 |
| 0 | 1 | 0 | 830 | 707 |
| 0 | 1 | 1 | 900 | 763 |
| 1 | 0 | 0 | 970 | 819 |
| 1 | 0 | 1 | 1040 | 876 |
| 1 | 1 | 0 | 970 | 819 |
| 1 | 1 | 1 | 1040 | 876 |

Comp Video Mode

### Control DACs

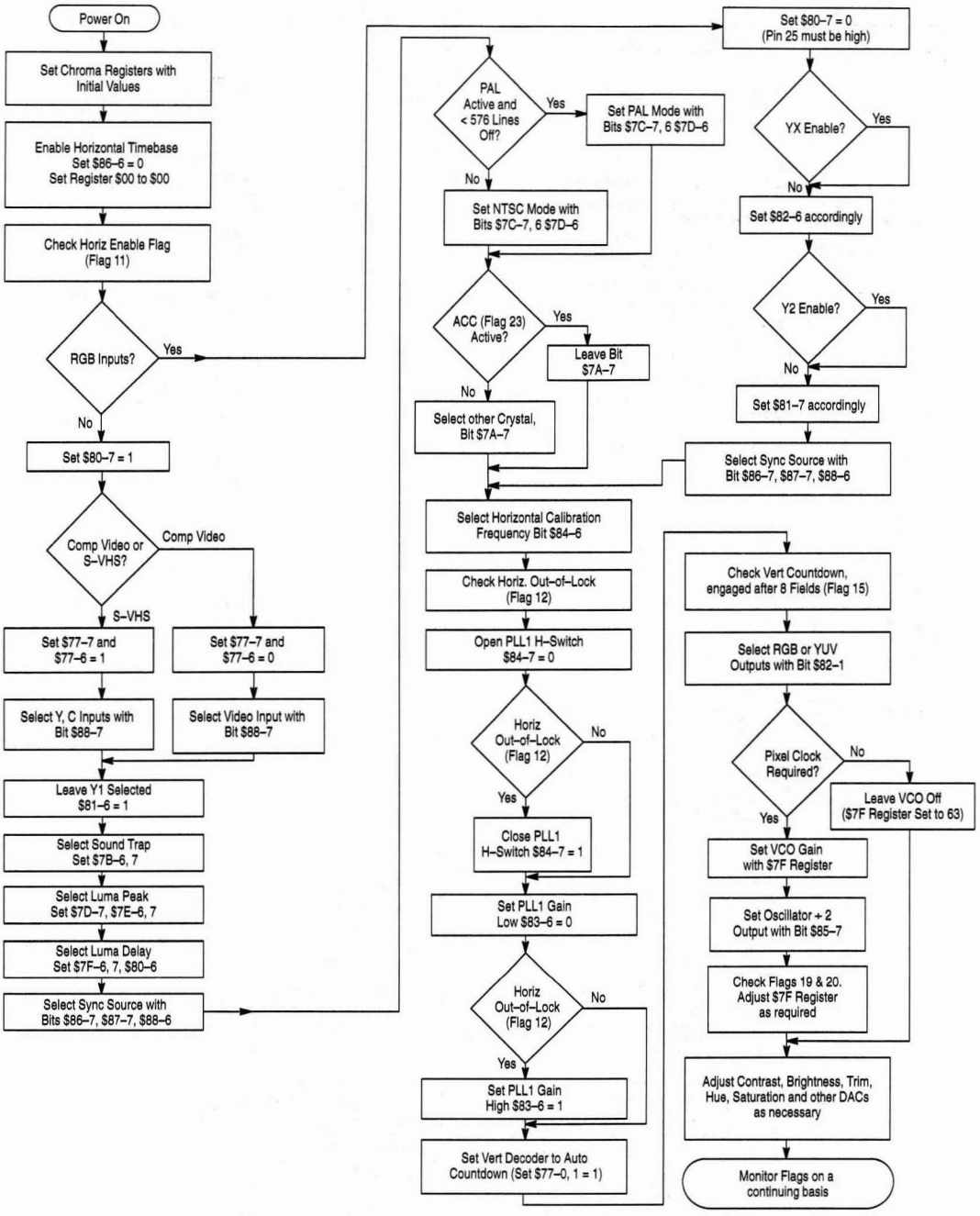
| | | | |
|---|---|---|---|
| $78 | R–Y/B–Y Gain Adjustment | $82 | Red Contrast Trim |
| $79 | Subcarrier Phase | $83 | Blue Brightness Trim |
| $7D | Blue DC Bias | $84 | Main Brightness |
| $7E | Red DC Bias | $85 | Red Brightness Trim |
| $7F | Pixel Clock VCO Gain | $86 | Saturation (Color Diff Section) |
| $80 | Blue Contrast Trim | $87 | Saturation (Decoder) |
| $81 | Main Contrast | $88 | Hue |

### Flags

| | | | |
|---|---|---|---|
| 10 | Internally Set to 1 | 19 | Pixel Clock VCO Gain too low |
| 11 | Horizontal Loop (PLL1) Enabled | 20 | Pixel Clock VCO Gain too high |
| 12 | Horizontal Loop not Locked | 21 | Internally Set to 1 |
| 13 | Internally Set to 0 | 22 | Internally Set to 0 |
| 14 | Less than 576 Lines | 23 | ACC Loop Active |
| 15 | Vertical Decoder Engaged | 24 | PAL Signals Detected |
| 16 | Internally Set to 1 | 25 | Not Used |
| 17 | Internally Set to 1 | 26 | Internally Set to 0 |

## APPENDIX B

### Suggested Mode Setting Routine (Simplified)


Power On
Set Chroma Registers with Initial Values
Enable Horizontal Timebase Set $86–6 = 0 Set Register $00 to $00
Check Horiz Enable Flag (Flag 11)
RGB Inputs?
Yes
No
Set $80–7 = 1
Comp Video or S–VHS?
Comp Video
S–VHS
Set $77–7 and $77–6 = 1
Set $77–7 and $77–6 = 0
Select Y, C Inputs with Bit $88–7
Select Video Input with Bit $88–7
Leave Y1 Selected $81–6 = 1
Select Sound Trap Set $7B–6, 7
Select Luma Peak Set $7D–7, $7E–6, 7
Select Luma Delay Set $7F–6, 7, $80–6
Select Sync Source with Bits $86–7, $87–7, $88–6
Set $80–7 = 0 (Pin 25 must be high)
PAL Active and < 576 Lines Off?
Yes
Set PAL Mode with Bits $7C–7, 6 $7D–6
No
Set NTSC Mode with Bits $7C–7, 6 $7D–6
ACC (Flag 23) Active?
Yes
Leave Bit $7A–7
No
Select other Crystal, Bit $7A–7
Select Horizontal Calibration Frequency Bit $84–6
Check Horiz. Out–of–Lock (Flag 12)
Open PLL1 H–Switch $84–7 = 0
Horiz Out–of–Lock (Flag 12)
No
Yes
Close PLL1 H–Switch $84–7 = 1
Set PLL1 Gain Low $83–6 = 0
Horiz Out–of–Lock (Flag 12)
No
Yes
Set PLL1 Gain High $83–6 = 1
Set Vert Decoder to Auto Countdown (Set $77–0, 1 = 1)
YX Enable?
Yes
No
Set $82–6 accordingly
Y2 Enable?
Yes
No
Set $81–7 accordingly
Select Sync Source with Bit $86–7, $87–7, $88–6
Check Vert Countdown, engaged after 8 Fields (Flag 15)
Select RGB or YUV Outputs with Bit $82–1
Pixel Clock Required?
No
Yes
Leave VCO Off ($7F Register Set to 63)
Set VCO Gain with $7F Register
Set Oscillator ÷ 2 Output with Bit $85–7
Check Flags 19 & 20. Adjust $7F Register as required
Adjust Contrast, Brightness, Trim, Hue, Saturation and other DACs as necessary
Monitor Flags on a continuing basis

## APPENDIX C

## I²C Description

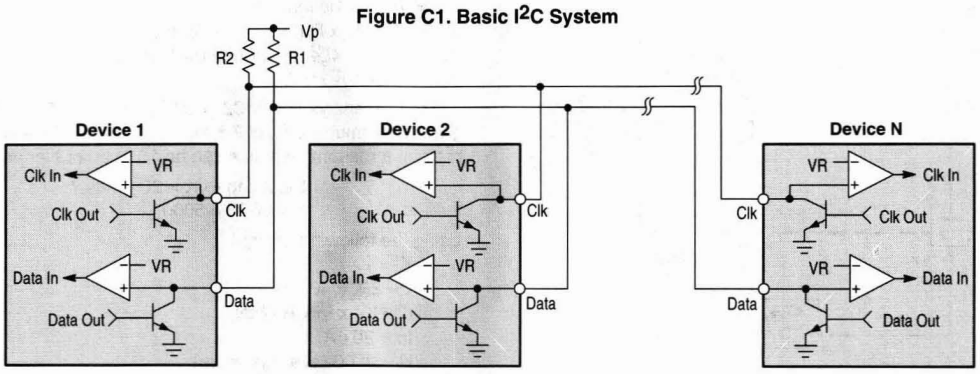
### Introduction

The I²C system, a patented and proprietary system developed by Philips Corporation, defines a two–wire communication system. The number of devices in a system is limited only by the system capacitance and data rate. Each device is assigned two unique addresses – one for writing to it, and one for reading from it. Any device may act as a master by initiating a data transfer with any other device (the slave). Data transfer is in 8–bit bytes, and can be in either direction, but not in both directions in one data transfer operation.

### Hardware Aspects

The system bus consists of two wires, Clock and Data. All devices must have open–collector (or open–drain) outputs. A single pull–up resistor is required on each line, as shown in Figure C1.

**Figure C1. Basic I²C System**




Devices such as the MC44011, which never act as a master, need not have the output drive transistor at the Clock pin. Nominal value for R1 and R2 is 10 kΩ, but can be different to account for system capacitance at high data rates. VR is a switching threshold for input signals.

The significant electrical characteristics are as follows:

- Maximum data rate (Clock frequency) is 100 kHz;
- $V_{OL}$ max is 0.4 V when sinking 3.0 mA;
- $V_{IL}$ max is 0.3 x Vp, but at least 1.5 V;
- $V_{IH}$ min is 3.0 V for a 5.0 V system, or 0.7 x Vp for other supply voltages.
- The maximum input current at Clock and Data at $V_{OL}$ max (when they are inputs) is –10 μA;
- The maximum input current at Clock and Data at 0.9 x Vp (when they are inputs) is 10 μA;
- The maximum pin capacitance is 10 pF;
- Maximum bus capacitance is 400 pF.

### Data Transfer

Prior to initiating a data transfer, both lines must be high (all drive transistors off). A device which initiates a data transfer assumes the role of the master, and generates a START condition by taking the Data line low while Clock is still high. At this time, all other devices become listeners. The master will supply the clock for the entire sequence.

The master then sends the 8–bit address by operating both the clock and data lines. Data must be stable during the clock's high time, and can change during the clock's low time. The MSB is sent first. The address must end in a 0 if it is a Write operation (data transfer from master–to–slave), and it must end in a 1 if it is a Read operation.

At the 9th Clock Pulse, the master must release the Data line high, and the slave must provide an acknowledge bit by pulling Data low during this clock time. If the master does not receive a proper acknowledge, it can terminate the operation.

After the first acknowledge, the role of the two devices depends on whether it is a Write or a Read operation, but the master always supplies the clock.

- In a Write operation the master is the transmitter, and the slave is the receiver.
- In a Read operation the slave is the transmitter, and the master is the receiver.

The transmitter then sends the next 8–bit byte. At the 18th Clock Pulse (and every 9th clock pulse thereafter), the transmitter releases the Data line, and the receiver acknowledges by pulling Data low. There is no limit to how many bytes may be sent after the address.

When all data is transferred, the Data line must be released by the transmitter so that the master can set the STOP condition. This is done by first pulling Data low (during clock low), then releasing Data high while clock is high. After this, the bus is free for any other device to initiate a new data transfer.

### Definitions

**Master** – The device which initiates a data transfer (regardless of the data direction), generates the clock, and terminates the transfer.

**Slave** – The device addressed by the master.

**Transmitter** – The device which supplies data to the bus.

**Receiver** – The device which receives data from the bus.

Notice that the master is not necessarily the transmitter, and the slave is not necessarily the receiver.

### Other

For additional information on the I²C bus specifications; modes of operation; arbitration; and synchronization, contact Philips Corporation.

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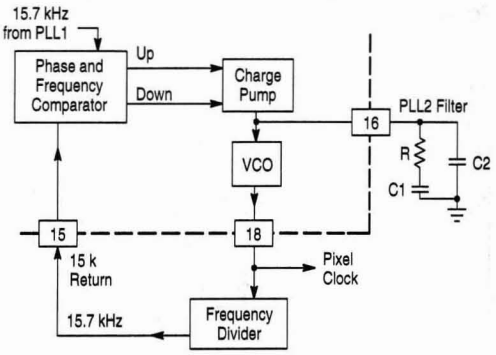
## APPENDIX D

## PLL Loop Theory

### High Frequency Line–Locked Clock Generator

This section is not intended as a complete loop theory, its aim is merely to point out the idiosyncrasies of the loop, and provide the user with enough information for the selection of filter components. For a more in depth explanation, the references at the end of this section may be consulted.

**Figure D1. PLL2 Basic Configuration**




The following general remarks apply to the loop (PLL2):
- The loop frequency is ≈ 15.7 kHz.
- In spite of the samples nature of the loop, a continuous time approximation is possible if the loop bandwidth is sufficiently small.
- Ripple on $V_C$ (filter pin) is a function of loop bandwidth.
- The loop is a type II, 3rd order. However, since C2 is small, the pole it creates is far removed from the low frequency dominant poles, and the loop can be analyzed as a 2nd order loop.

The following remarks apply to the Phase and Frequency Comparator:
- Phase and frequency sensitive.
- Independent of duty cycle.
- It has 3 allowed states: up, down, and off (high impedance).
- The VCO is always pulled in the right direction during acquisition.
- The Comparator's gain is higher at or near lock.

The last two remarks imply that only the higher value need be taken into account, as acquisition will be slower but always in the correct direction, whereas the higher gain will come into action as soon as the error reaches $2\pi$.

The following values are selected and defined:
C2 = C1/10 or less, to satisfy the requirement that the effect of C2 on the low frequency response of the loop be minimal, and similar to a 2nd order loop.

$\xi$ = 0.707 (damping factor).
$\omega i$ = 15750 x 2p = 98960 rad/sec (input frequency).
$\tau$ = RC as the loop filter
K = Ko x Ip x R/(2πN) – the loop gain
K′ = K x $\tau$ = $4\xi^2$ (the normalized loop gain)
Ko = 70 x $10^6$ rad/V

Stability analysis with C2 = C1/10 and K′ = 2 ($\xi$ = 0.707) gives a minimum value of 7.5 for the ratio $\omega i$/K. To have some margin, a reasonable value can be 15 to 20 or higher.

Selecting $\omega i$/K = 20 yields,
K = $\omega i$/20 ≈ 5000.

Using the following items:
K′ = 2,
$\tau$ = 2/K = 400 µs,
K = Ko x Ip x R/(2πN)
Ip = 20 µA
N = 2000 (average value)

yields a value of 22 kΩ for R. Using a value of 400 µs for $\tau$, C1 calculates to 18 nF, and C2 calculates to 1.8 nF.

With the above values, the loop's natural frequency ($\omega$n), and loop bandwidth ($\omega$3dB) can be calculated:
$\omega$n = {(Ko/N) x Ip/(2πC) }$^{0.5}$ = 3520 rad/sec.
fn = 3520/2π = 560 Hz.
$\omega$3dB ≈ 2 x $\omega$n = 1120 Hz (valid if $\xi$ = 0.707).

The circuit designer should be cautioned at this point that the above calculated values are not necessarily optimum for every application. Besides the fact that several assumptions were made in the discussion, the equations cannot account for items such as the PC board layout, characteristics of the external divider, and noise from various sources. The above calculated values provide for a functional circuit, which should then be tweaked to obtain minimum jitter at the pixel clock output.

When initially adjusting the filter component values, it is advisable to maintain the same general time constant (400 µs in this example), and the same x10 relationship between C1 and C2.

References:
(1) *Charge–Pump Phase–Lock–Loops* by Floyd M. Gardner, IEEE Transactions on Communications, Vol. com–28, no. 11, Nov. 1980.
(2) *Phaselock Techniques* by Floyd M. Gardner, J. Wiley & Sons, 1979.
(3) *Phase–Locked–Loops* by Roland E. Best, McGraw Hill, 1984.
(4) AN–535, *Phase–Locked–Loop Design Fundamentals*, Motorola.

## GLOSSARY

**Aspect Ratio** – The ratio of the width of a TV screen to the height. In standard TVs, it is 4:3. In HDVT it will likely be 16:9.

**Back Porch** – The blanking time after the sync signal during which the color burst is inserted.

**Blank, Pedestal** – The signal level which is either at black, or slightly more negative than black ("blacker–than–black"), and is used to turn off the screen dot during retrace. Also referred to as the *pedestal.*

**Brightness** – A measure of the dc levels of the luma component. Changing brightness will change the minimum and maximum luma levels together.

**Burst** – The 8 to 10 cycle sine wave which is inserted in the back porch. It's frequency is the color subcarrier (3.58 MHz or 4.43 MHz), and is used as a phase reference for the color decoder.

**Burst Gate** – A signal identifying the time during which the burst signal occurs.

**C, Chrominance** – The color component of the video signal. The color is determined by the phase of the chrominance component relative to the burst signal.

**Clamping** – A process which establishes a fixed dc voltage level, usually during the back porch time.

**Color Difference Signals** – B–Y, R–Y, also designated as U and V.

**Color Decoder** – A circuit which separates composite video into Red, Blue, and Green, luminance, and sync signals.

**Color Encoder** – A circuit which combines Red, Blue, and Green, luminance, and sync signals into composite video.

**Comb Filter** – A multi–bandpass filter which separates the luma and chrominance components from the video signal, without sacrificing bandwidth.

**Component Video, YUV** – A format whereby the video information is kept as separate luma, R–Y, and B–Y signals *(YUV).* U is the same as B–Y, and V is the same as R–Y.

**Composite Sync** – A sync signal which combines horizontal and vertical sync information. The waveform is made up of regularly spaced negative going pulses for the horizontal sync, and then half–line pulses and polarity reversal to indicate the vertical sync and retrace time.

**Composite Video** – The video signal which consists of sync, back porch, color burst, video information (luma and chroma), and front porch. This is the signal normally broadcast by TV stations.

**Contrast** – A measure of the difference between minimum and maximum luma amplitudes. Increasing contrast produces a "blacker" black and a "whiter" white.

**dB** – A power or voltage measurement unit, referred to another power or voltage. It is generally computed as:

10 x log (P1/P2) for power measurements, and
20 x log (V1/V2) for voltage measurements.

**Field** – One of the two or more equal parts into which a frame is divided in an interlaced system.

**Frame** – The information which makes up one complete picture. It consists of 525 lines in NTSC systems, and 625 lines in PAL systems. An interlaced system is typically composed of two fields.

**Front Porch** – The blanking time immediately before the sync signal.

**Horizontal Sync** – The negative going sync pulses at the beginning of each line. The pulses indicate to the circuit to begin sweeping the dot across the screen.

**Hue** – A measure of the correctness of the colors on a screen.

**Interlaced System** – A method of generating a picture on the screen whereby the even number lines are processed, and then the odd number lines are processed, thereby completing a full picture.

**IRE** – Abbreviation for *International Radio Engineers*, it is the amplitude unit used to define video levels. In standard NTSC signals, blank–to–white is 100 IRE units, and blank–to–sync tip is 40 IRE units. In a 1.0 Vpp signal, one IRE unit is 7.14 mV.

**Luma, Y** – The brightness component of the video signal. Usually abbreviated "Y", it defines the shade of gray in a black–and–white TV set. In color systems, it is composed of 0.30 red, 0.59 green and 0.11 blue.

**NTSC** – *National Television System Committee.* This committee set the color encoding standards and format for television broadcast in the United States.

**PAL** – *Phase Alternating Line.* A color encoding system in which the burst is alternated 90° each line to help compensate for color errors which may occur during transmission. This system is popular mainly in Europe.

**Pixel** – The smallest picture element, or dot, on a screen. It is determined by the design of the CRT, as well as the system bandwidth.

**R–Y, B–Y** – Referred to as *color difference signals.* These are two of the three signals of component video. When combined with Y, the full color and luminance information is available.

**Retrace** – The rapid movement of the blanked dot from the screen's right edge to the left edge so it can start scanning a new line. It is also the rapid movement from the lower right corner to the upper left corner during vertical blanking.

**RGB** – The three main colors *(red, blue, green)* used in the acquiring, and subsequent display of a video signal.

**S–VHS** – A format whereby the video information is kept as separate luma and chroma signals (Y and C).

**Sandcastle** – A signal which indicates the horizontal blanking time. It encompasses the front porch, sync, and back porch. Two amplitudes distinguish the front porch + sync time from the back porch.

**Saturation** – A measure of the intensity of the color on a screen. Also related to its purity.

**Sync Separator** – A circuit which will detect, and output, the sync signal from a composite video waveform.

**Vertical Sync** – The synchronizing signal which indicates to the circuitry to drive the dot to the upper left corner of the screen, thereby starting a new field. This signal is derived from the composite sync.

MOTOROLA

# MC44030
# MC44035

*Product Preview*

## Multistandard Video Signal Processor with Integrated Chroma Delay Line

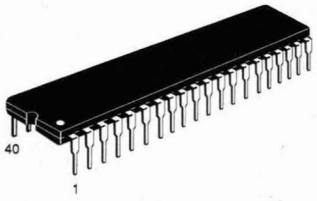
The MC44030/35 is a highly advanced circuit which performs most of the basic functions required for a color TV. All its advanced features are under processor control via $I^2C$ bus, enabling potentiometer controls to be removed completely and allowing significant cost savings together with the possibility of implementing sophisticated automatic test routines.

A summary of the features available on the device is given below:

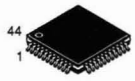
- Operation from a Single 5.0 V Supply; Low Current Consumption (Typically 150 mA)
- PAL/SECAM/NTSC Decoding Capability (4 Matrix Modes Available)
- Integrated Chroma Delay Line
- Dual Composite Video or S–VHS Inputs
- Integrated Luma and Chroma Filters (Including SECAM Cloche Filter)
- Programmable Luma Delay and Peaking
- RGB Drives Including CONTRAST/BRIGHTNESS Controls and Auto Grey–Scale
- External RGB and Fast Commutate Inputs with SATURATION Control Possibility
- Auxiliary Y, R–Y, B–Y Inputs
- Line Timebase Featuring H–PHASE Control and Switchable Phase Detector Gain
- Countdown Type Vertical Timebase Including the Vertical Geometry Corrections
- 16:9 Display Mode Capability
- E–W Parabola Drive Including the Horizontal Geometry Corrections
- Anode Current Monitor with Vertical Breathing Compensation
- Analog Contrast Control, Allowing Fast Beam Current Limitation
- Pin to Pin Compatible with MC44002/7
- MC44035 is the PAL/NTSC Only Version of the MC44030
- Available in DIP and TQFP Packages

**MULTISTANDARD VIDEO SIGNAL PROCESSOR WITH INTEGRATED CHROMA DELAY LINE**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 711



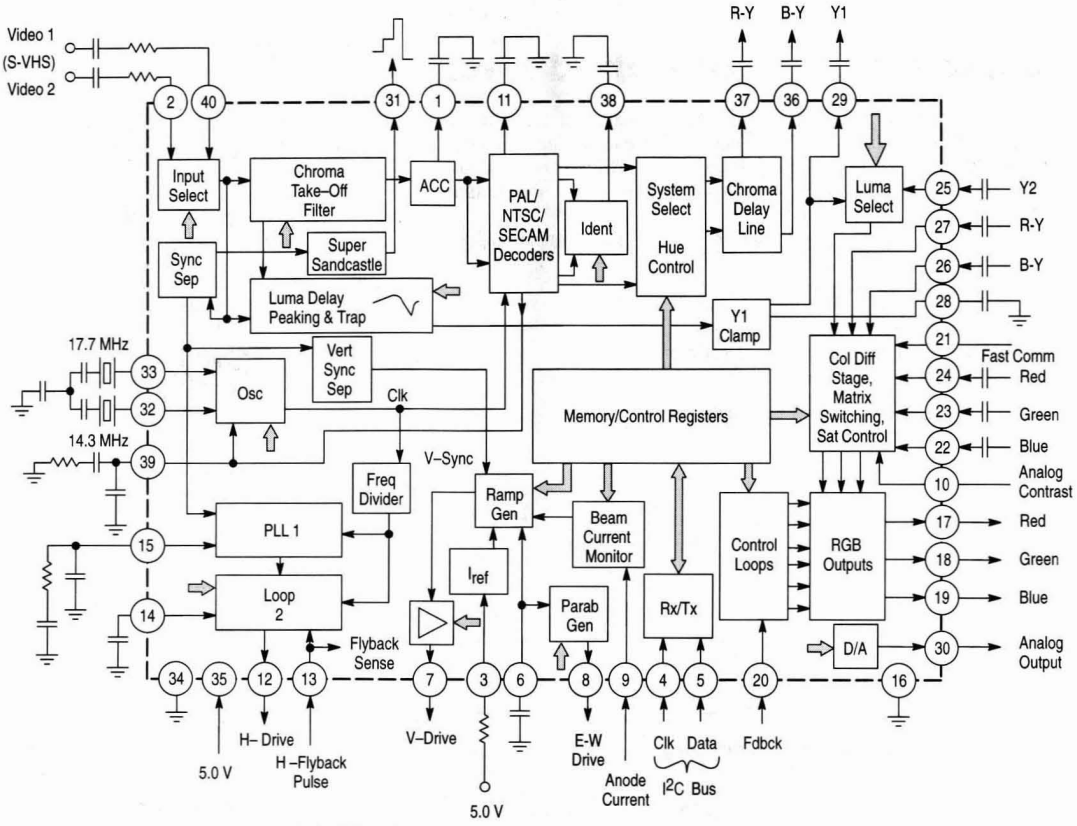

**FTB SUFFIX**
PLASTIC PACKAGE
CASE 824D
(TQFP–44)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44030P | $T_A$ = 0° to +70°C | Plastic DIP |
| MC44030FTB | | TQFP–44 |
| MC44035P | | Plastic DIP |
| MC44035FTB | | TQFP–44 |

9

## Simplified Block Diagram




**NOTE:** Pin numbers shown are for the DIP package.

This device contains 6360 active transistors.

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MOTOROLA

# MC44144

## Subcarrier Phase-Locked Loop

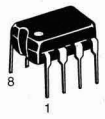
The MC44144 is a gated phase–locked loop intended for, but not restricted to, video applications. The integrated circuit contains a gated phase detector, voltage controlled crystal oscillator, divide–by–4 circuitry, and a video clamp. This device provides a 4X reference frequency output, and a 1X reference frequency output.

The MC44144 is manufactured using Motorola's high density, bipolar MOSAIC™ process.

- 8–Pin DIP or Surface Mount Package
- Gated–Phase Detector
- Single Pin Voltage Controlled Crystal Oscillator
- 1X and 4X Subcarrier Output
- Operates Off of a Standard 5.0 V Supply

**SUBCARRIER PHASE–LOCKED LOOP**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

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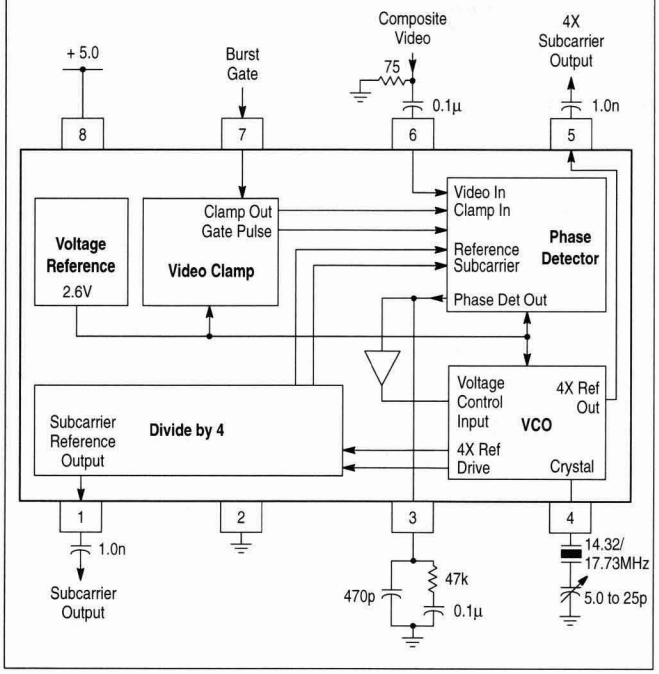
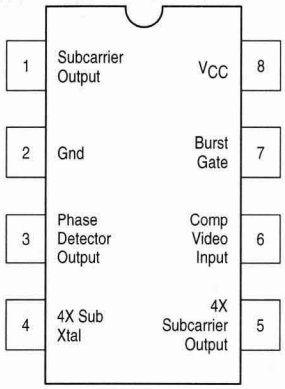
**Representative Block Diagram**




**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44144D | $T_A$ = 0° to +70°C | SO–8 |
| MC44144P | | Plastic |

## ABSOLUTE MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 6.0 | Vdc |
| Operating Ambient Temperature | $T_A$ | 0° to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to +150 | °C |
| Operating Junction Temperature | $T_J$ | +150 | °C |

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Pin | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Supply Voltage | 8 | $V_{CC}$ | 4.5 | 5.0 | 5.5 | Vdc |
| Composite Video Input (Note 1)<br>Burst Amplitude to Acquire Lock | 6 | – | 50 | 300 | 1000 | mVpp |

**NOTE:** 1. Total peak–to–peak voltage of video should not exceed ground or $V_{CC}$.

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = 5.0 Vdc, $T_A$ = 25°C)

| Characteristic | | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Operating Current | | 8 | 8.0 | 10 | 12 | mA |
| Burst Gate Threshold Voltage: | $V_{IH}$ | 7 | 3.0 | – | – | Vdc |
| | $V_{IL}$ | | – | – | 1.5 | |
| Burst Gate Input Current: | $I_{IH}$ ($V_{in}$ = 5.0 V) | | – | – | 20 | µA |
| | $I_{IL}$ ($V_{in}$ = 0 V) | | – | – | –0.5 | |
| 4X Subcarrier | | 5 | | | | |
| Output Voltage: (14.32 MHz) | | | 400 | 610 | 650 | mVpp |
| (17.73 MHz) | | | – | 450 | – | |
| Output Impedance: (14.3 MHz and 17.73 MHz) | | | – | 25 | – | Ω |
| Subcarrier Output | | | | | | |
| Output Voltage: (3.58 MHz and 4.43 MHz) | | | 200 | 300 | 400 | mVpp |
| Output Impedance: (3.58 MHz and 4.43 MHz) | | 1 | – | 200 | – | Ω |
| Phase Angle (Note 1) | | | – | –60 | – | deg |
| Phase Sensitivity (Notes 1 & 2) | | | – | 3.0 | – | Note 2 |
| Static Phase Error (Note 2) | | 1, 2 | – | 3 | – | deg/100 Hz |
| Phase–Locked Loop Pull–In Range | | | – | ± 350 | – | Hz |
| Phase–Locked Loop Hold–In Range | | | – | ± 500 | – | |

**NOTES:** 1. Referenced to composite video input color burst.
2. See paragraph 1 of the Functional Description text.

**Figure 1. Typical VCXO Gain**

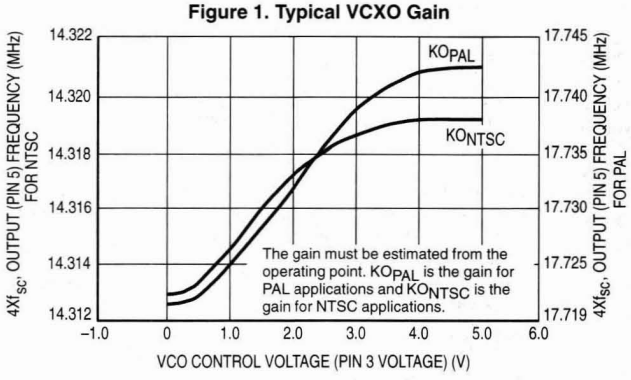



**Table 1. Crystal Specifications**

| | |
|---|---|
| Frequency | 14.31818 MHz (NTSC)<br>17.734475 MHz (PAL) |
| Mode | Fundamental |
| Frequency Tolerance<br>@ 25°C<br>df/dfo 0°C – 70°C | 40 ppm |
| Load Capacitance | 20 pF |
| ESR | 50 Ω |
| C1 (Internal Series Capacitance) | 15 mpF |

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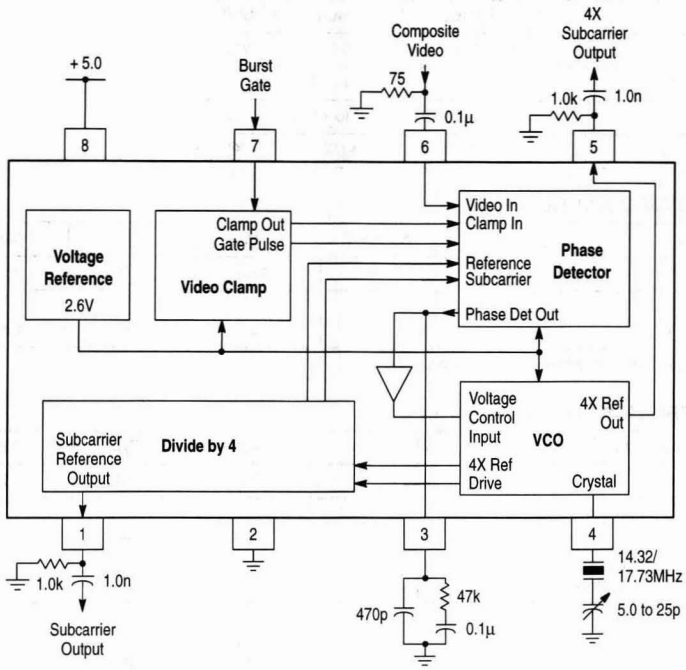
**Figure 2. Representative Schematic Diagram**




## FUNCTIONAL DESCRIPTION

The MC44144 is designed to implement the color sync function in a video system. When provided NTSC/PAL composite video or composite chroma and burst gate inputs, the IC will phase–lock a Voltage Controlled Crystal Oscillator (VCXO) to the color burst. Both 4X and 1X subcarrier frequency outputs are provided by the IC. The VCXO operates off of a 4X subcarrier crystal and The VCXO operates off a 4X subcarrier crystal and is capable of at least ± 600 Hz of pull–in. The tradeoff for such a wide pull–in range is a resultant "soft" lock, or a 3° phase shift per 100 Hz *change* in oscillator free–run or input reference frequency.

In addition to providing the gate pulse for the MC44144 phase detector, the Burst Gate input also initiates a clamp pulse that sets up the level of the composite video at the input to the Phase Detector. The start and duration of the Gate Pulse should be timed so that the pulse envelopes the color burst of the video signal, but not so wide as to gate sync or video into the Phase Detector.

The Phase Detector is enabled when the voltage at the Burst Gate input (Pin 7) is above the nominal 2.2 V threshold. While this makes possible the ability to lock to a color burst, it does not exclude the possibility of lock to a constant reference. If a constant source is to be the reference, the Phase Detector can be permanently enabled by holding the voltage on the Phase Detector input pin higher than the threshold voltage.

The phase detector gain must be specified in two ways, for a constant reference and for a burst–locked application. The gain in a constant reference application is specified by the maximum current output with the maximum phase error. For a maximum phase error of $\pi/2$ radians the maximum current available is approximately 200 µA. So the phase detector gain is defined as,

$$KPD = 200/(\pi/2)(\mu A/rad \bullet sec)$$

For a burst–locked application, the Phase Detector is active for only the duration of the color burst. Therefore the phase detector gain must be specified as an average gain over a line period. In this case the phase detector gain for NTSC and for PAL applications is,

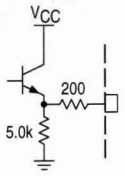
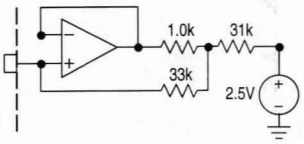
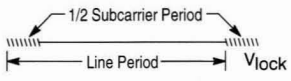
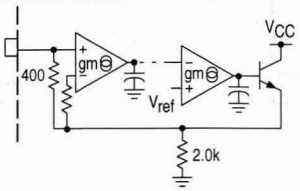
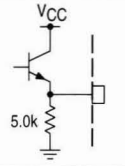
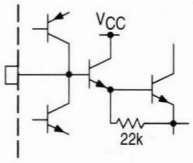
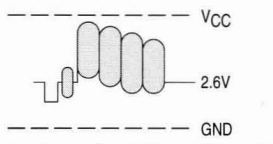
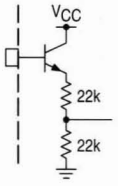
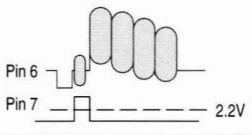
$$KPD_{NTSC} = (8/(\pi/2))(\mu A/rad \bullet sec) \text{ and,}$$
$$KPD_{PAL} = (7/(\pi/2))(\mu A/rad \bullet sec)$$

A suitable filter for both types of applications is shown in the test schematic Figure 2. This same filter also works for both NTSC and PAL applications.

The 4X subcarrier Voltage Controlled Crystal Oscillator (VCXO) uses a design that enables the use of series or parallel resonant types of crystals. Still, layout and crystal positioning are critical as the oscillator frequency is sensitive to shunt capacitance. Care should be taken to keep the crystal close to the IC and crystal switching should be avoided. A suitable parallel type crystal would meet the specifications in Table 1.

A plot showing the VCXO gain is shown in Figure 1. From this plot the gain must be estimated from the operating point. $KO_{PAL}$ is the gain for PAL applications and $KO_{NTSC}$ is the gain for NTSC applications.

## PIN FUNCTION DESCRIPTION

| Name | Pin | Representative Circuitry | Description | Expected Waveforms |
|---|---|---|---|---|
| Subcarrier Output | 1 |  | Subcarrier Output. A phase–locked reference of the PAL or NTSC color burst is output at this pin. | A 300 mVpp square wave is output. Some high frequency content is present. |
| Ground | 2 | | Circuit Ground | |
| Phase Detector Output | 3 |  | The error current from the phase detector is output at this pin. A filter circuit should be connected at this pin. | A beat waveform, showing both horizontal period and half the subcarrier period, is present.<br>  |
| 4X Sub Xtal | 4 |  | Crystal Oscillator Pin. A 4X subcarrier parallel resonant crystal, in series with a 5.0 to 25 pF trimmer capacitor provides the resonant element for the Voltage Controlled Crystal Oscillator (VCXO). | Approximately 40 mVpp. A scope probe will disturb the frequency of oscillation. |
| 4X Subcarrier Output (or Black Burst) | 5 |  | Buffered output from the 4X voltage controlled oscillator. | The sinusoidal $4Xf_{SC}$ oscillator output is available at this pin.<br>The output is nominally:<br>525 mVpp for NTSC,<br>425 mVpp for PAL. |
| Composite Video Input (Black Burst, Continuous Wave, or Composite Chroma can also be applied) | 6 |  | Composite Video Input. Color burst from the video present at this pin is used as a reference to phase lock the VCXO. Positive or negative video may be used. | Composite video should be applied at this pin. The color burst amplitude of the input video should be at least 50 mV, but no more than 1000 mV. The waveform at this pin should not exceed ground or $V_{CC}$.<br>  |
| Burst Gate Input | 7 |  | Input for the phase detector gate pulse. TTL compatible. The threshold is nominally 2.6V. | A positive going gate pulse should be applied at this pin. The Burst Gate input should envelope the color burst.<br>  |
| $V_{CC}$ | 8 | | Power Supply Pin. 5.0 Vdc should be applied at this pin. | |

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## Linear and TTL Output Buffers

The output buffers of the MC44144 are not designed to any specific logic family. If it is desired, Linear or TTL buffers can be added externally. Figure 3 shows an example of a Linear buffer using an MC3346 Transistor array; virtually any utility transistor can be used. Figure 4 shows a TTL type buffer using an MC74LS04 buffer.

**Figure 3. Linear Buffer**

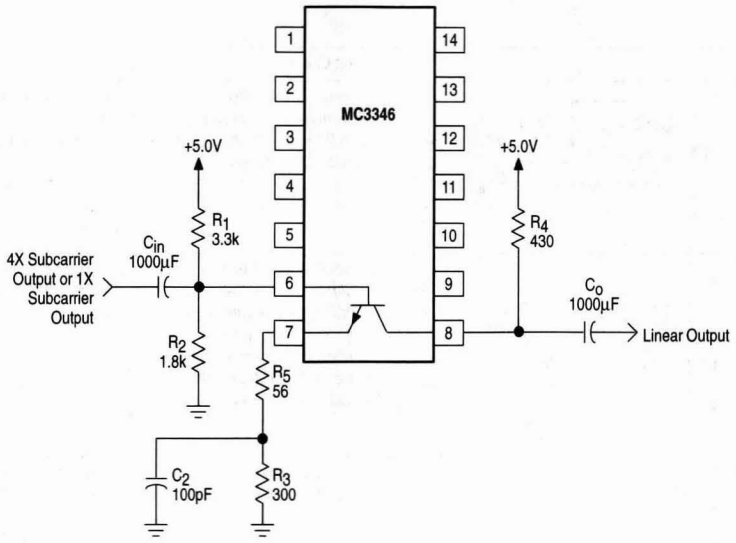
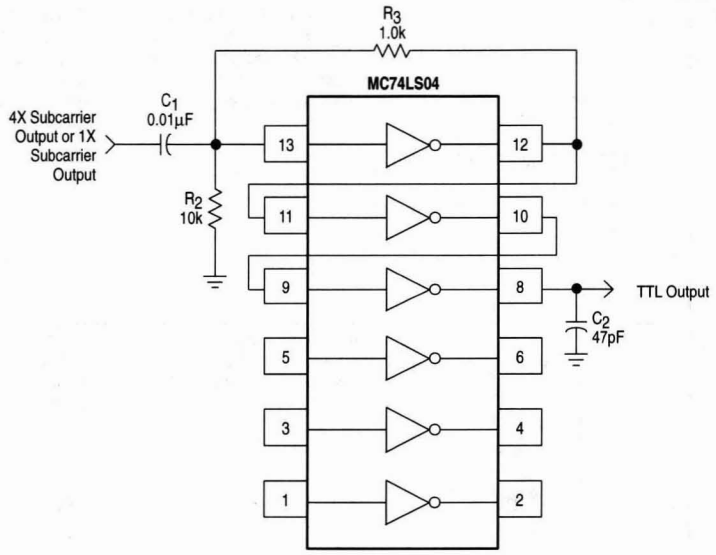



**Figure 4. TTL Buffer**



MOTOROLA

# MC44145

## Pixel Clock Generator/ Sync Separator

The MC44145, Pixel Clock Generator, is a component of the MC44000 family.

The MC44145 contains a sync separator with composite sync and vertical outputs, and clock generation circuitry for the digitization of any video signal along with the necessary circuitry for clock generation, such as a phase comparator and a divide–by–2 to provide a 50% duty cycle.

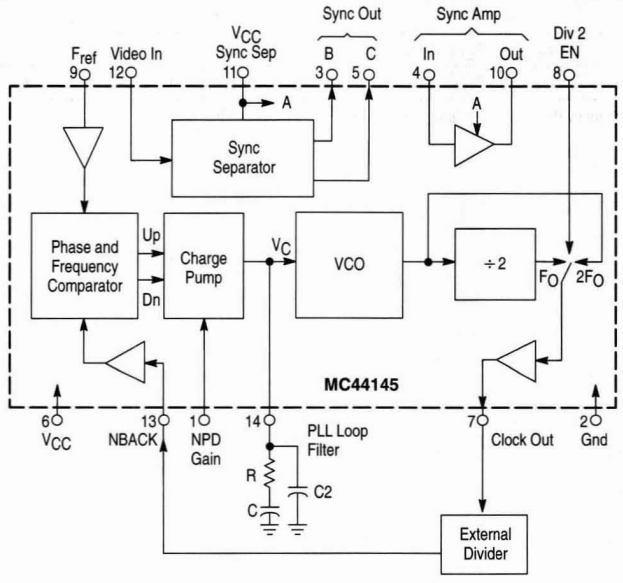
The MC44145 is available in a SO–14 package and is fabricated in the Motorola high density, high speed, low voltage, process called MOSAIC 1.5®.

**PIXEL CLOCK GENERATOR/ SYNC SEPARATOR**

**SEMICONDUCTOR TECHNICAL DATA**

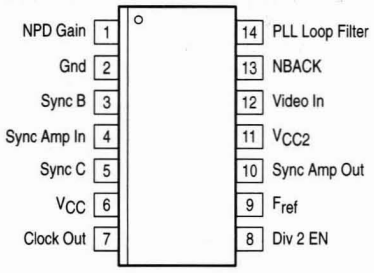
**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**Representative Block Diagram**




This device contains 214 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44145D | $T_A$ = 0° to +70°C | SO–14 |

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## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$<br>$V_{CC2}$ | 6.0<br>6.0 | V |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |
| Operating Junction Temperature | $T_J$ | +150 | °C |

**NOTE:** ESD data available upon request.

## RECOMMENDED OPERATING CONDITIONS

| Characteristic | Symbol | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Supply Voltage | $V_{CC}$<br>$V_{CC2}$ | 6<br>11 | 4.75<br>4.75 | 5.0<br>5.0 | 5.5<br>5.5 | Vdc |
| Video Input Amplitude (Note 2) | $V_{in}$ | 12 | 0.4 | 1.0 | 2.5 | Vpp |
| NBACK Pulse Width | NBACK | 13 | 100 | 500 | – | ns |
| $F_{ref}$ Pulse Width | $F_{ref}$ | 9 | 100 | 500 | – | ns |
| Operating Ambient Temperature | $T_A$ | – | 0 | – | +70 | °C |

## ELECTRICAL CHARACTERISTICS

| Characteristic | Symbol | Note | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | | | |
| Supply Current (Note 1) | $I_{CC}$ | – | 6 | – | 15.5 | – | mA |
| Supply Current | $I_{CC2}$ | – | 11 | – | 300 | – | µA |
| **SYNC SEPARATOR** ($V_{CC}$ = 5.0 V; $T_A$ = 25°C, unless otherwise specified.) | | | | | | | |
| Sync B Output | – | 3 | 3 | – | 5.0 to 0 | – | V |
| Sync C Output (1.0 mA Source) | – | 4 | 5 | – | 0 to 3.3 | – | V |
| Slicing Level ($S_L$) | – | – | 12 | – | $V_{CC/2}$ | – | V |
| Video Input Sink Current | – | $V_{Pin\ 12} < S_L$ | 12 | – | 18 | – | µA |
| Video Input Source Current | – | $V_{Pin\ 12} > S_L$ | 12 | – | 1.2 | – | µA |

**NOTES:** 1. Operating current for Pin 6 is dependent on the clock frequency (Pin 7). Values given are specified for Pin 14 = 4.0 V.
2. Positive Video.
3. High impedance output.
4. Low impedance output.

**ELECTRICAL CHARACTERISTICS (continued)**

| Characteristic | Note | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **SYNC SEPARATOR** ($V_{CC}$ = 5.0 V; $T_A$ = 25°C, unless otherwise specified.) | | | | | | |
| **VCO** ($V_{CC}$ = 5.0 V; $T_A$ = 25°C, unless otherwise specified, divider disabled.) | | | | | | |
| $F_{min}$ | 1, 5 | 7, 8, 14 | – | – | 10 | MHz |
| $F_{max}$ | 1, 4 | 7, 8, 14 | 39 | 42 | – | MHz |
| Control Range | 2 | 14 | 1.0 | – | 4.0 | V |
| Transfer Function | 1 | 7, 8, 14 | – | 14 | – | MHz/V |
| Input Resistance | 9 | 14 | 0.5 | – | – | MΩ |
| Charge Pump | 6<br>7 | 1, 14 | –<br>– | 40<br>80 | –<br>– | µA |
| Phase Jitter | 8 | 7, 9 | – | – | 3.0 | ns |
| **INPUT BUFFERS ($F_{ref}$ AND NBACK)** ($T_A$ = 25°C, unless otherwise specified.) | | | | | | |
| Threshold (TTL Compatible) | – | 9, 13 | – | 2.5 | – | V |
| Input Current | – | 9, 13 | – | – | 1.0 | µA |
| **OUTPUT BUFFER CLOCK** ($T_A$ = 25°C, unless otherwise specified.) | | | | | | |
| Sync Amplifier Output High Level | 1.0 mA Source | 10 | 2.4 | 3.0 | – | V |
| Sync Amplifier Output Low Level | 1.0 mA Sink | 10 | – | 0.2 | 0.4 | V |
| Rise Time | 11 | 10 | – | – | 6.0 | ns |
| Fall Time | 11 | 10 | – | – | 6.0 | ns |
| Load Capacitance | 10 | 10 | – | 15 | – | pF |

**NOTES**: 1. Internal divider disabled.
2. 0 V stops the oscillator.
3. Divider ÷2 active.
4. $V_C$ = 4.0 V.
5. $V_C$ = 1.0 V.
6. PFD gain low.
7. PFD gain high.
8. VCO alone.
9. $V_C$ = 4.0 V, charge pumps off.
10. 2 LSTTL loads.
11. With cap load 15 pF and between 10 and 90% of 0.4 and 2.4 V.

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## CIRCUIT DESCRIPTION

### Composite Sync Separator

The composite sync separation section is comprised of two blocks, a sync slicer and a sync amplifier, which can be used to extract the vertical sync and composite sync information from a video signal.

The sync separator is an adaptive slicer in which the video signal is slightly integrated and then sliced at a ratio of 4.7 to 64 which corresponds to the sync to horizontal ratio. Two outputs are given, one of high impedance and the other low impedance.

A slicing sync inverting amplifier is also on–chip, allowing one output to be used for composite sync and the other output to be integrated and then sliced using the slicing amplifier to extract the vertical sync information.

### Clock Generation

The clock generation is made up of a wide ranging emitter–coupled VCO followed by a switchable ÷2 to provide a 50% duty cycle wherever required, or twice the set frequency if an external divider is used. The clock generator is a PLL subsection; its function is the generation of a high frequency, line locked clock that is used for video sampling and digitizing.

The clock output is a LSTTL–like buffer which has a limited drive capability of two LSTTL loads.

The VCO is driven from a charge pump with selectable current. The charge pump is driven by the phase comparator.

The phase comparator is a type IV "phase and frequency comparator" sequential circuit.

The clock generator, the heart of a PLL, is to be closed by means of an external divider, thus setting the synthesized frequency. This divider could be implemented in discrete logic or be a part of an ASIC subsystem.

### Phase and Frequency Comparator

The phase comparator is fed from two input buffers, $F_{ref}$ which expects a reference frequency at line rate and that is rising edge sensitive, and NBACK which comes from the external divider and is falling edge sensitive.

Charge pump current and output divider action are controlled by applying suitable voltage on the appropriate pins (respectively, NPD Gain and Div 2 EN).

### PIN FUNCTION DESCRIPTION

| Pin | Function | Description |
|---|---|---|
| 1 | NPD Gain | This pin sets the gain of the phase frequency detector by changing the current of the charge pump output (40 µA or 80 µA). Low current with this pin > 2.0 V, high current for < 0.5 V. |
| 2 | Ground | Ground connection common to the PLL and sync separator sections. |
| 3 | Sync B | High impedance sync output. |
| 4 | Sync Amp In | Sync amplifier input. |
| 5 | Sync C | Low impedance sync output. |
| 6 | $V_{CC}$ | Power connection to the PLL section. |
| 7 | Clock Out | VCO clock output. Capable of limited LSTTL drive. It should not be used to drive high capacitive loads, such as long PCB traces or coaxial lines. |
| 8 | Div 2 EN | The divider is switched in with this pin > 2.0 V; switched out for < 0.5 V. |
| 9 | $F_{ref}$ | Reference frequency input to the phase and frequency comparator. Typically this will be a 15625 (15750) Hz signal. It is rising edge sensitive. Due to the nature of the phase and frequency comparator, no missing pulses are tolerable on this input. In a typical setup, this signal can be provided by the MC44011. |
| 10 | Sync Amp Out | Sync amplifier output. |
| 11 | $V_{CC2}$ | Power connection to the sync separator and amplifier. |
| 12 | Video In | Video signal input to the sync separator. |
| 13 | NBACK | Fed by the external clock divider. Sets the multiplication ratio of the loop in multiples of the $F_{ref}$ frequency. Negative edge sensitive. |
| 14 | PLL Loop Filter | See loop filter calculations at the end of this document. |

**NOTE:** The two $V_{CC}$ pins are not independent, as they are internally connected by means of the input protection diodes; they must always be both connected to a suitable $V_{CC}$ line.

## CIRCUIT OPERATION

### Composite Sync Separator

The sync separator is an adaptive slicer. It will output "raw" sync data. Two outputs are given, thus allowing one output to be used for composite sync and the other output to be integrated and then sliced using the inverting slicing amplifier provided. As the input of the slicing amplifier is external, the amplifier may be driven from either sync output, although normally the high impedance output (Sync B) would be recommended.

The positive video input signal required is nominally 1.0 V sync–to–white, but the circuit supports signals above and below this level and also is resistant to a degree of reflections on the signal. Coupling to the sync separator may be achieved by a simple capacitor of 100 nF, but better results may be obtained with a higher value in series with a resistance of 1.0 kΩ.

### Clock Generator

The system is best put to use in a dual loop configuration; a first loop locks to line frequency by means of a type I phase detector (multiplier type) which is insensitive to missing pulses. This PLL is then followed by a second loop using the MC44145, performing frequency multiplication. The phase comparator of the MC44145 is frequency and phase sensitive. It is a type IV (sequential type) phase detector, which does not tolerate missing pulses. The dual loop structure makes up a noise insensitive frequency (and phase) locked loop.

The phase and frequency comparator provides two logical outputs, mutually exclusive – up or down – that are used to source or sink current to and from the loop filter. This current can be user–selected to be 40 μA or 80 μA (typical), thus providing some degree of loop gain control.

The VCO is an emitter–coupled multivibrator type, with an on–chip timing capacitor, and has been designed for low phase noise.

The divide–by–2 is included at the output of the VCO, thus allowing for a precise 50% duty cycle, hence the VCO is operating at twice the required frequency. The divider can be bypassed, bringing the VCO output directly to the output buffer.

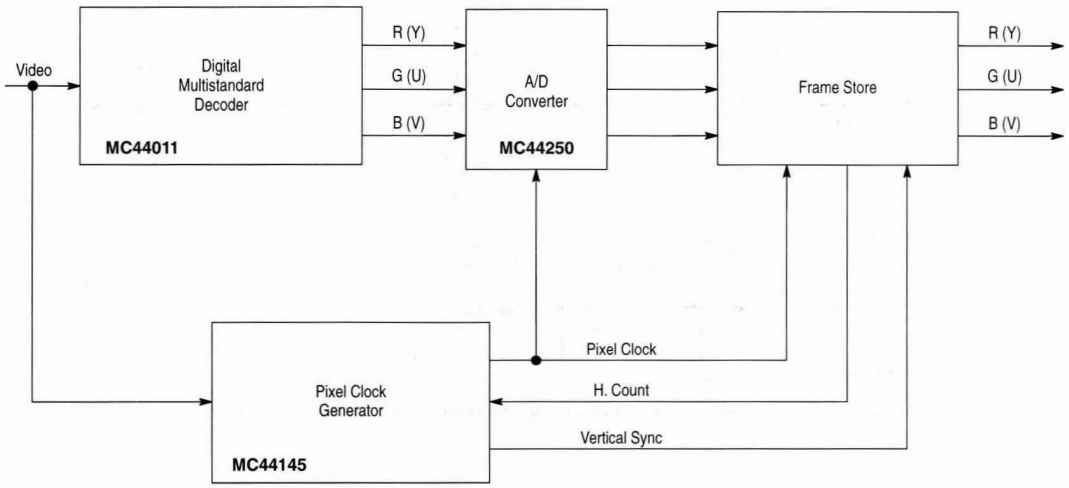
The external divider must provide a feedback pulse to close the loop; the falling edge of this pulse will be aligned (when the loop is in lock) with the rising edge of the pulse applied to the $F_{ref}$ input. Operation of the phase comparator is insensitive to the duty cycle of both its inputs. The feedback pulse should have a minimum width of 500 ns. This can be guaranteed if it has a length of at least 16 output clock cycles (highest output frequency with the divider disabled).

## APPLICATION INFORMATION

Analog video signals out of the MC44011 are sampled and converted to 8–bits digital in the A/D converter (MC44250 series) by means of the clock provided by the MC44145, pixel clock generator (see Figure 1).

The frame store contains the memory, the necessary logic for the memory addressing, as well as the counter to set the frequency multiplication ratio of the line locked clock generator (H. Count).

**Figure 1. Application Block Diagram**




9

**Figure 2.**

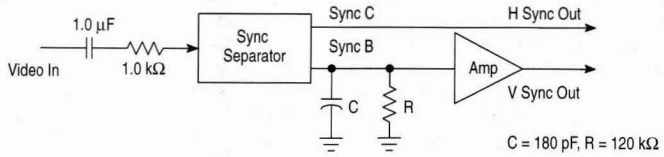



**Figure 3. Typical VCO Transfer Characteristics**

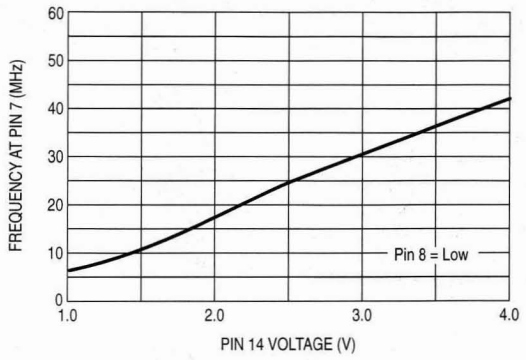
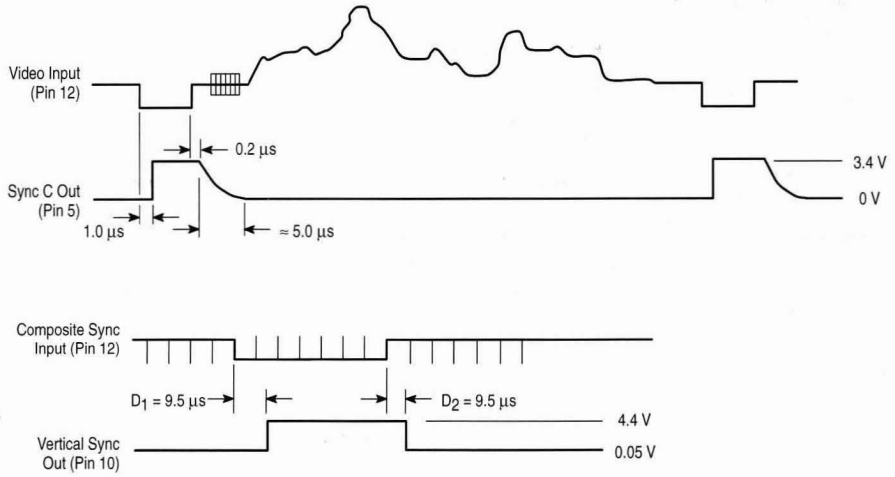



**Figure 4. Sync Separator Timing**




**Note:** $D_1$ and $D_2$ depend on the value of R and C connected to Pin 3. They are specified here for the values: R = 120 kΩ, and C = 180 pF.

## LOOP FILTER CALCULATION

This section is not intended as a complete loop theory; its aim is merely to point out the peculiarities of the loop, and provide the user with enough information for the filter components selection. For a more in–depth covering, the cited reference should be consulted, especially [1].

The following remarks apply to the loop:

- The loop frequency is 15 kHz.
- In spite of the sampled nature of the loop, a continuous time approximation is possible if the loop bandwidth is sufficiently small.
- Ripple on $V_C$ is a function of the loop bandwidth
- The loop is a type II, 3rd order; however, since C2 is small, the pole it creates is far removed from the low frequency dominant poles, and the loop can be analyzed as a 2nd order loop.

These remarks apply to the PFD:

- Phase and frequency sensitive.
- Independent of duty cycle.
- PFD has 3 allowed states: up, down, hi–Z
- The VCO is always pulled in the right direction (during acquisition).
- PFD gain is higher near lock.

The last two remarks imply that only the higher value need be taken into account, as acquisition will be slower, but always in the proper direction, whereas the higher gain will enter the action as soon as the error reaches $\pm 2\pi$.

The following values are selected and defined (see Block Diagram):

C2 = C/10 or less, to satisfy the requirement that the effect of C2 on the low frequency response of the loop be minimal, and similar to a second order loop.

$\zeta = 0.707$ for the damping factor.

$\omega i = 15625 \times 2\pi$ the input pulsation.

$\tau = RC$ as the loop filter.

$K = Ko \times Ip \times R/(2 \times \pi \times N)$ the loop gain.

$K' = K \times \tau = 4\zeta^2$ is the "normalized" loop gain.

$Ko = 57 \times 10^6$ [rad/Vs] (9.0 MHz/V).

Stability analysis, with C2 = C/10 and $K' = 2$ ($\zeta = 0.707$) gives a minimum value of 7.5 for the ratio $\omega i/K$ and to have some margin, a reasonable value can be 15 to 20 or higher [1].

Selecting $\omega i/K = 20$, gives : $K = \omega i/20 \approx 5000$.

With $K' = 2$, $\tau = 2/K = 400\ \mu s$.

Using $K = Ko \times Ip \times R/(2 \times \pi \times N)$ and setting $Ip = 60\ \mu A$, and N an average value of 1000, we get $R = 9.1\ k\Omega$.

Then for $\tau = 400\ \mu s$, C becomes 47 nF and C2, 4.7 nF.

With these values, the loop natural frequency ($\omega n$) and the loop bandwidth ($\omega 3dB$) can be calculated:

$\omega n = [(Ko/N) \times Ip/(2\pi C)]^{1/2} = 3400$ and

$fn = 3400/2\pi = 540$ Hz.

$\omega 3dB = 2 \times \omega n = 1080$ Hz (valid if $\zeta$ is close to 0.707).

**References:**

[4] Charge–Pump Phase–Lock Loops, Floyd M. Gardner, IEEE transactions on communications, vol. com–28 no. 11 November 1980

[5] Phaselock Techniques, Floyd M. Gardner, J. Wiley & Sons, 1979

[6] Phase–Locked Loops, Roland E. Best, McGraw–Hill, 1984

[7] Phase–Locked Loop Systems, Motorola

MOTOROLA

# MC44353
# MC44354
# MC44355

*Product Preview*

# PLL Tuned UHF Audio/Video Modulator ICs for PAL, SECAM and NTSC TV Systems

**MC44353 – Multi–Standard Modulator IC**
**MC44354 – PAL/NTSC Modulator IC**
**MC44355 – PAL/NTSC Modulator IC with Fixed Video Modulation Index**

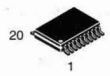
**MULTI–STANDARD AND PAL/NTSC MODULATOR ICs**

**SEMICONDUCTOR TECHNICAL DATA**

These modulator circuits are intended for use in VCRs, satellite receivers, set–top boxes, video games, etc. An on–chip high speed $I^2C$ compatible bus receiver is included and is used to set the channel, tuned by a PLL over the full range in the UHF bands. The modulator incorporates a sound subcarrier oscillator, using a second PLL to derive 4.5, 5.5, 6.0 and 6.5 MHz carrier frequencies, selectable by the bus.

For the sound, either frequency modulation with pre–emphasis or amplitude modulation (MC44353 only) is possible. A control bit (MC44353 only) is used to select AM sound with positive RF modulation (system L). The level of the sound carrier with respect to the vision carrier and the modulation depth of both sound and vision may be adjusted by means of the bus. In addition, an on–chip video test pattern generator may be switched in with a 1.0 kHz audio test signal.

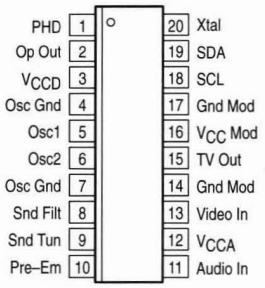
- UHF Operation (471 MHz to 855 MHz)
- On–Chip Low Power Operational Amplifier for Direct Tuning Voltage Output
- Single–Ended Output for Low Cost and Ease of Interface
- Low External Component Count
- High Speed $I^2C$ Bus Compatible (Min 500 kHz)
- Programmable Video Modulation Depth (8 Steps of 2.5%)
- Programmable Picture/Sound Carriers Ratio and Audio Sensitivity (8 Steps of 1.0 dB)
- Programmable Sound Subcarrier Oscillator (4.5 MHz to 6.5 MHz)
- Video Test Pattern Generator with Sound Test Signal (1.0 kHz)
- $V_{CC}$ Standby Mode (Typ 500 µA)
- Transient Output Inhibit During PLL Lock–Up at Power–On




**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948E
(TSSOP–20)

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44353DTB | $T_A$ = –20° to +80°C | TSSOP–20 |
| MC44353DW | | SO–20L |
| MC44354DTB | | TSSOP–20 |
| MC44354DW | | SO–20L |
| MC44355DTB | | TSSOP–20 |
| MC44355DW | | SO–20L |

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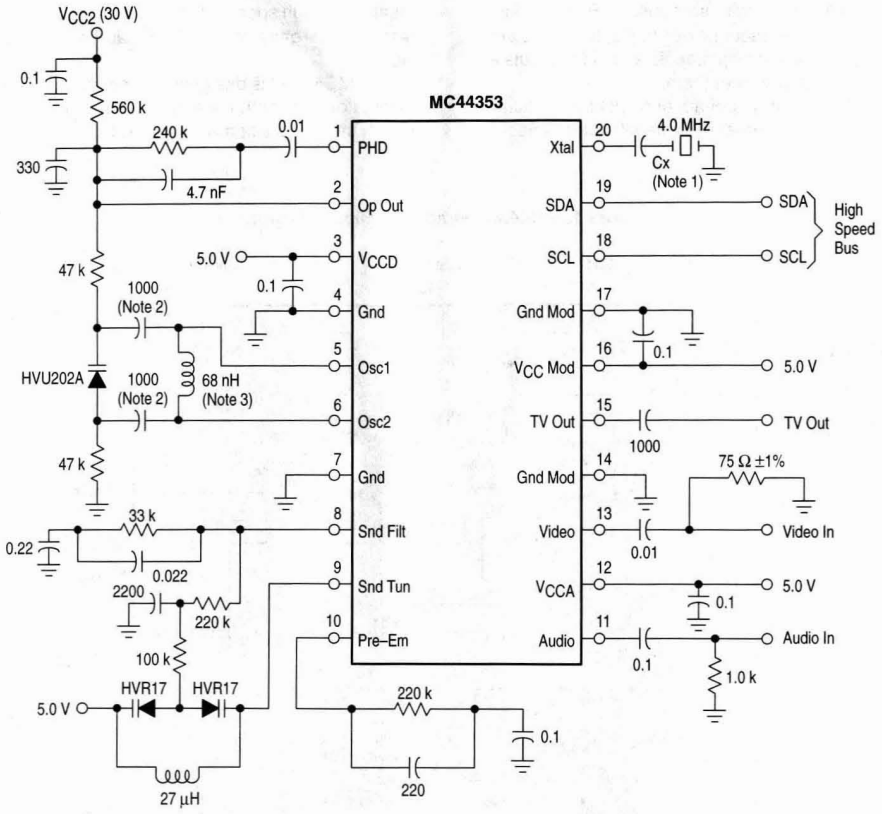
## Typical Application




**NOTES:** 1. Cx depends on Crystal Load Capacitance, Crystal resistance < 200 Ω.
2. Tubular 0603 1000 pF capacitors.
3. UHF Coil is a surface mount 0805 Chip Inductor, REF: AVX/KYOCERA – L0805 6R8 DEW ±0.5 nH (@ 450 MHz Q = 43, @ 900 MHz Q = 62 and L = 7.0 nH)

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## MODULATOR FUNCTIONAL DESCRIPTION

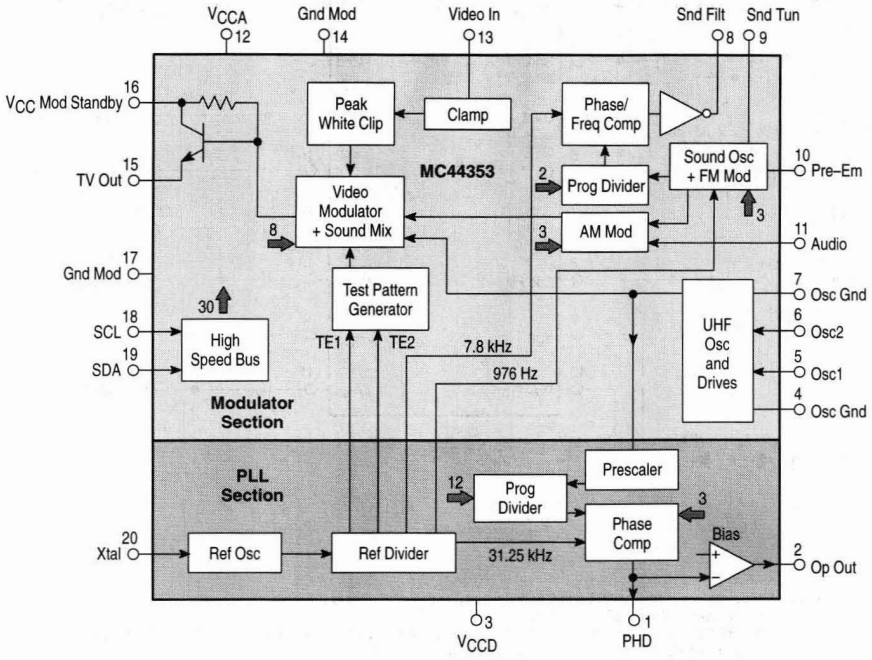
### General

The device has two main sections; a PLL section to synthesize the channel frequency of the UHF output and a modulator section which accepts audio and video inputs and modulates the UHF carrier with them.

The channel frequency, sound and picture modulation index and sound/picture carrier ratio are all programmable by means of a high speed I²C compatible bus. An on–chip video test pattern generator with an audio test signal is also included.

The MC44353 is designed to operate as a multi–standard modulator and can handle the systems B/G, D/K, H, I, L and N with the same external circuit components.

**Figure 1. MC44353 Simplified Block Diagram**

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MOTOROLA

# MC44461

*Advance Information*

## Picture-in-Picture (PIP) Controller

**PICTURE–IN–PICTURE (PIP) CONTROLLER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC44461 Picture–in–Picture (PIP) controller is a member of Motorola's low cost PIP family. It is NTSC compatible and contains all the analog signal processing, control logic and memory necessary to provide for the overlay of a small picture from a second non synchronized source onto the main picture of a television. All control and setup of the MC44461 is via a standard two pin $I^2C$ bus interface. The device is fabricated using BICMOS technology. It is available in a 56–pin shrink dip (SDIP) package.

The main features of the MC44461 are:

- Two NTSC CVBS Inputs
- Switchable Main and PIP Video Signals
- Single NTSC CVBS Output Allows Simple TV Chassis Integration
- Two PIP Sizes; 1/16 and 1/9 Screen Area
- Freeze Field Feature
- Variable PIP Position in 64–X by 64–Y Steps
- PIP Border with Programmable Color
- Programmable PIP Tint and Saturation Control
- Automatic Main to PIP Contrast Balance
- Vertical Filter
- Integrated 64 k Bit DRAM Memory Resulting in Minimal RFI
- Minimal RFI Allows Simple Low Cost Application into TV
- $I^2C$ Bus Control – No External Variable Adjustments Needed
- Operates from a Single 5.0 V Supply
- Economical 56–Pin Shrink DIP Package

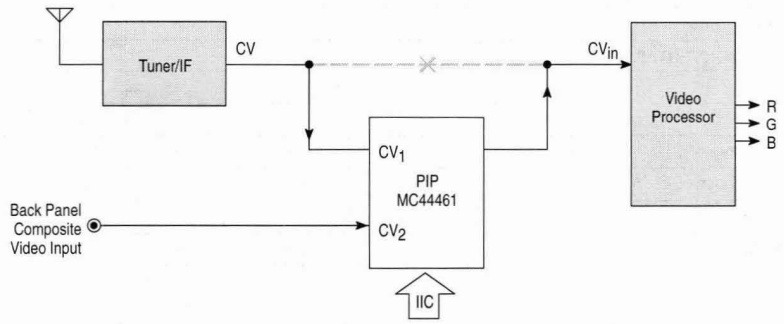
**B SUFFIX**
PLASTIC PACKAGE
CASE 859
(SDIP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44461B | $T_J$ = –65° to +150°C | SDIP |

For surface mount package availability, contact your local Motorola sales office or authorized distributor.

**Composite Video Simplified System Diagram**



## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{DD}$ | –0.5 to +6.0 | V |
| Power Supply Voltage | $V_{CC}$ | –0.5 to +6.0 | V |
| Input Voltage Range | $V_{IR}$ | –0.5, $V_{DD}$ + 0.5 | V |
| Output Current | $I_O$ | 160 | mA |
| Power Dissipation<br>Maximum Power Dissipation @ 70°C<br>Thermal Resistance, Junction–to–Air | <br>$P_D$<br>$R_{\theta JA}$ | <br>1.3<br>59 | <br>W<br>°C/W |
| Junction Temperature (Storage and Operating) | $T_J$ | –65 to +150 | °C |

**NOTE:** ESD data available upon request.

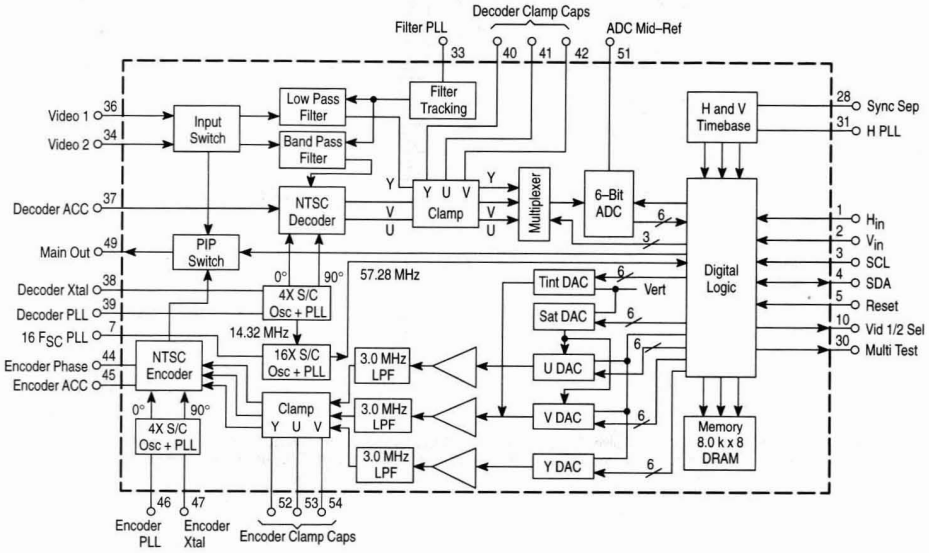
## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | |
| Total Supply (Pins 8, 15, 43 and 50) | Total $I_{Supply}$ | – | 100 | 160 | mA |
| **VIDEO** | | | | | |
| Composite Video Input (Pin 34 or 36) | CVi | – | 1.0 | – | Vpp |
| Composite Video Output (Pin 49, Unterminated) | – | – | 2.0 | – | Vpp |
| Video Output DC Level (Sync Tip) | – | – | 1.0 | – | Vdc |
| Video Gain | – | – | 6.0 | – | dB |
| Video Frequency Response (Main Video to –1.0 dB) | – | – | 10 | – | MHz |
| Color Bar Accuracy | – | – | ±4.0 | – | deg |
| Video Crosstalk (@ 75% Color Bars)<br>Main to PIP<br>PIP to Main | – | <br>–<br>– | <br>55<br>55 | <br>–<br>– | dB |
| Output Impedance | – | – | 5.0 | – | Ω |
| **HORIZONTAL TIMEBASE** | | | | | |
| Free Run HPLL Frequency (Pin 16) | – | – | 15734 | – | Hz |
| HPLL Pull–In Range | – | – | ±400 | – | Hz |
| HPLL Jitter | – | – | ±4.0 | – | ns |
| Burst Gate Timing (from Trailing Edge Hsync, Pin 24) | – | – | 1.0 | – | µs |
| Burst Gate Width | – | – | 4.0 | – | µs |
| **VERTICAL TIMEBASE** | | | | | |
| Vertical Countdown Window | – | – | 232/296 | – | H lines |
| Vertical Sync Integration Time | – | – | 31 | – | µs |
| **ANALOG TO DIGITAL CONVERTER** | | | | | |
| Resolution | – | – | 6 | – | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| ADC – Y Frequency Response @ –5.0 dB | – | – | 1.0 | – | MHz |
| ADC – U, V Frequency Response @ –5.0 dB | – | – | 200 | – | kHz |
| Sample Clock Frequency (4/3 $F_{SC}$) | – | – | 4.773 | – | MHz |

**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

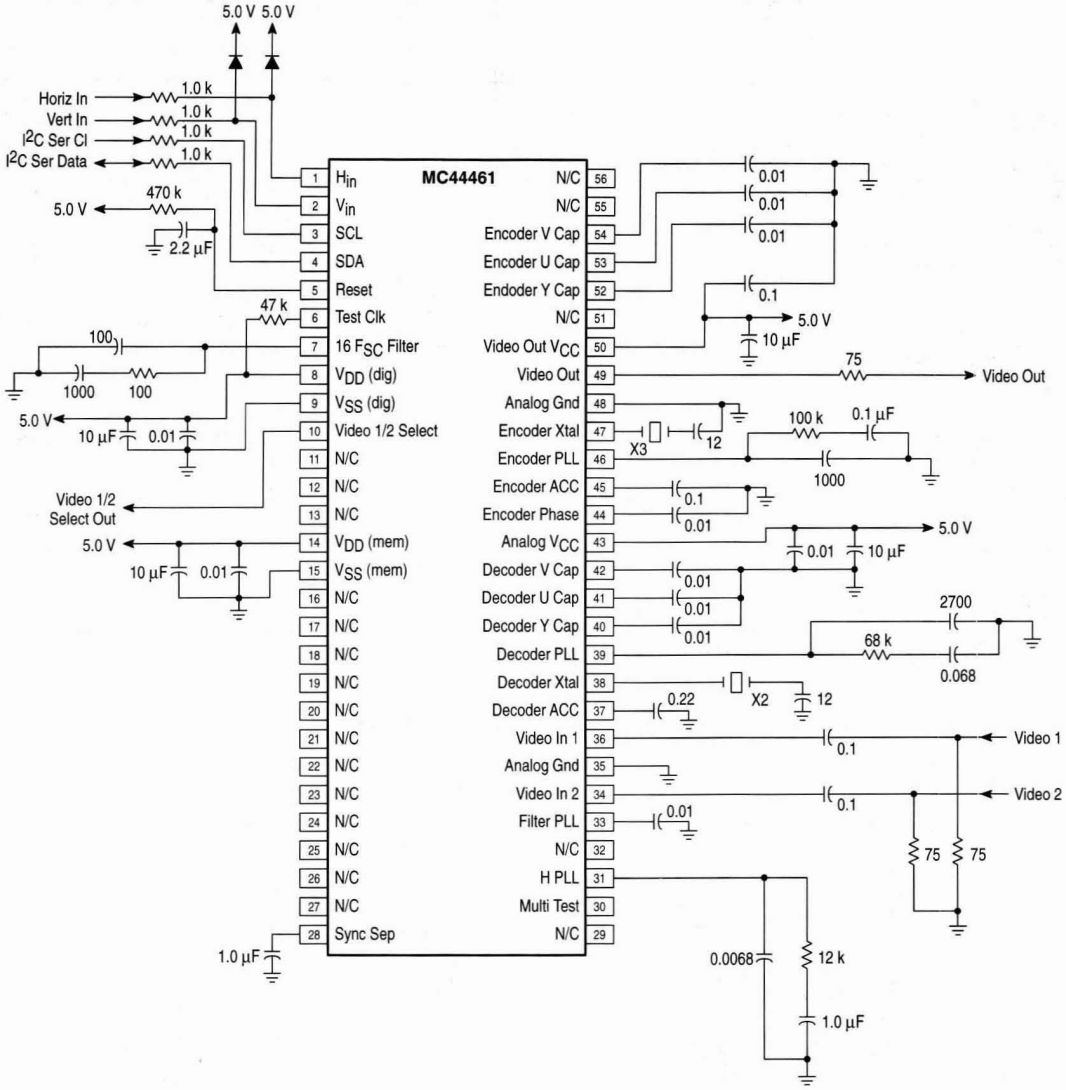
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DIGITAL TO ANALOG CONVERTER** | | | | | |
| Resolution | – | – | – | 6 | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| Tint DAC Control Range (in 64 Steps) | – | – | ±10 | – | Deg |
| Saturation DAC Control Range (in 64 steps) | – | – | ±6.0 | – | dB |
| **NTSC DECODER** | | | | | |
| Color Kill Threshold | – | – | –24/–16 | – | dB |
| Threshold Hysteresis | – | – | 3.0 ±1.0 | – | dB |
| ACC (Chroma Amplitude Change, +3.0 dB to –12 dB) | – | – | ±0.5 | – | dB |
| **PIP CHARACTERISTICS** | | | | | |
| PIP Size | – | | | | |
| 1/9 Screen Horizontal | | – | 114 | – | pels |
| 1/9 Screen Vertical | | – | 71 | – | lines |
| 1/16 Screen Horizontal | | – | 84 | – | pels |
| 1/16 Screen Vertical | | – | 53 | – | lines |
| Border Size Horizontal | – | – | 3 | – | pels |
| Border Size Vertical | – | – | 2 | – | lines |
| Output PEL Clock (4 $F_{SC}$) | – | – | 14.318 | – | MHz |
| Position Control Range Horizontal (% of Main Picture), 64 Steps | – | – | 100 | – | % |
| Position Control Range Vertical (% of Main Picture), 64 Steps | – | – | 100 | – | % |

**Figure 1. Representative Block Diagram**




This device contains approximately 500,000 active transistors.

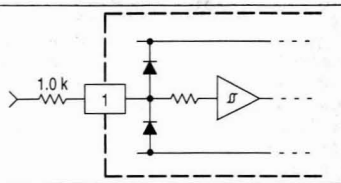
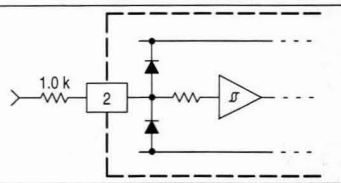
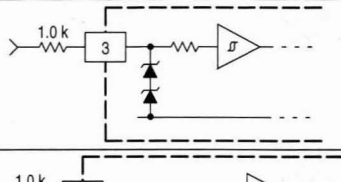
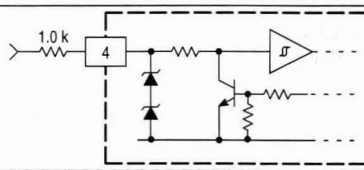
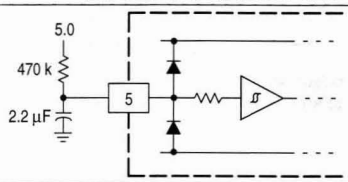
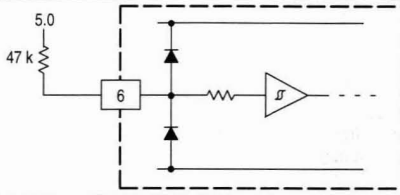
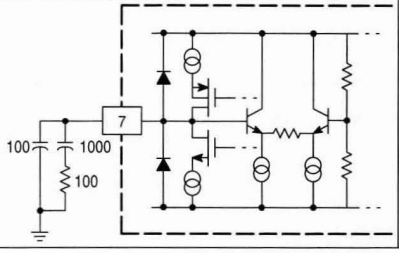
**Figure 2. Application Circuit**




X2 – 14.31818 MHz – Fox 143–20 or equivalent
X3 – 14.31818 MHz – Fox 143–20 or equivalent

**NOTE:** For proper noise isolation, Power Supply Pins 8, 14, 43 and 50 should be bypassed by both high and low frequency capacitors. As a guideline, a 10 µF in parallel with a 0.1 µF at each supply pin is recommended.

## PIN FUNCTION DESCRIPTION

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 1 |  | **Horizontal Reference In ($H_{in}$)**<br>CMOS level pulse synchronous with TV horizontal retrace signal. This pulse may be active high or low since there is a polarity selector bit in an internal control register. *This pulse should begin 0.5 to 0.75 µs after the beginning of the main video H sync period.* Its duty cycle should be less than 50%. |
| 2 |  | **Vertical Reference In ($V_{in}$)**<br>CMOS level pulse synchronous with TV vertical retrace signal. This pulse may be active high or low since there is a polarity selector bit in an internal control register. This pulse should begin during the main video vertical interval and have a duration of at least .5H. |
| 3 |  | **Serial Clock (SCL)**<br>CMOS level $I^2C$ Compatible slave only clock input. 100 kHz Maximum frequency. 50% duty cycle. See Figure 4 for timing. See $I^2C$ Register Description for internal register descriptions and addresses. |
| 4 |  | **Serial Data (SDA)**<br>CMOS level $I^2C$ Compatible slave only data input/output. As an output it is open collector. See Figure 4 for timing. See $I^2C$ Register Description for internal register descriptions and addresses. |
| 5 |  | **Reset**<br>The active low, Power On Reset initializes all internal registers to zero and resets the $I^2C$ interface. Minimum active low time required for Power On Reset reset is 100 ms. |
| 6 |  | **Test Clock** |
| 7 |  | **PLL Filter**<br>Filter for the 16X S/C PLL which is phase locked to the 4X S/C oscillator. |

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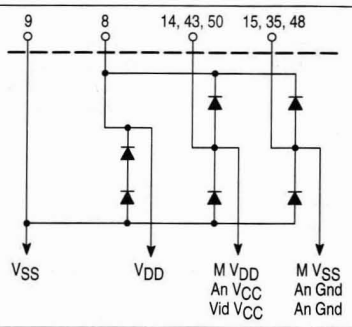
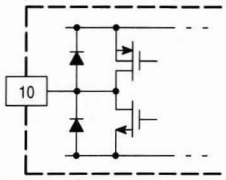
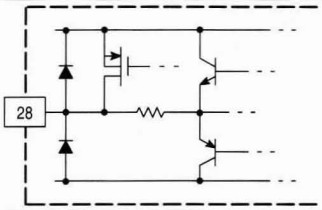
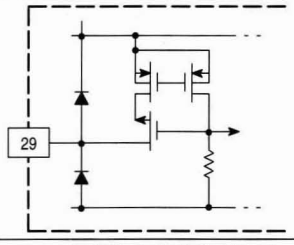
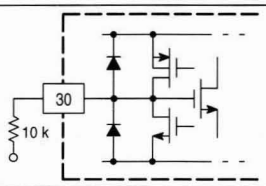
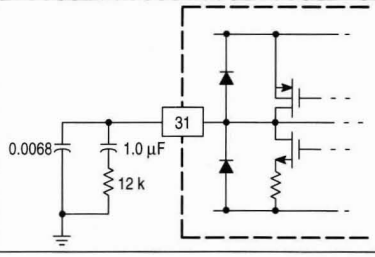
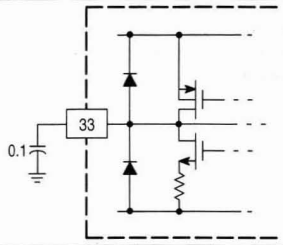
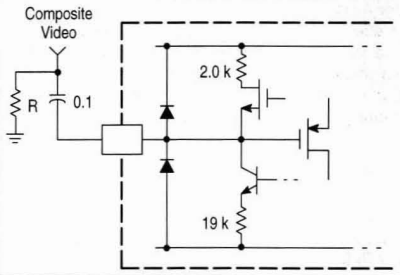
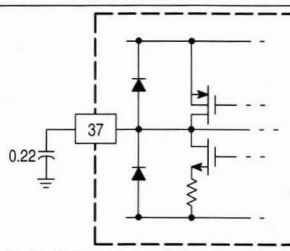
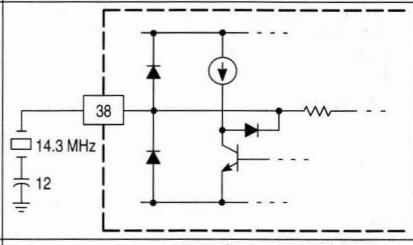
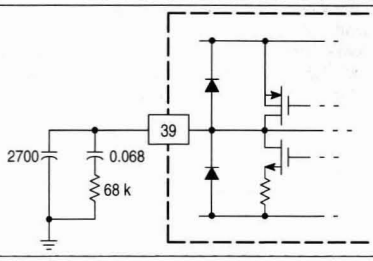
PIN FUNCTION DESCRIPTION (continued)

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 8<br>14, 43, 50<br>9<br>15, 35, 48 |  | **$V_{DD}$, $V_{SS}$**<br>The four $V_{DD}$ pins must be externally connected to a 5.0 V (±5%) supply. The four $V_{SS}$ lines must externally connect to their respective $V_{DD}$ bypass return(s) to ensure that no ground disturbances occur in operation. All supplies must be properly bypassed and isolated for the application. Bypass capacitors of 10 µF in parallel with 0.1 µF for each supply are recommended as a general guideline. The 0.1 µF, high frequency bypass capacitors should be placed as close to the power pins as practical. |
| 10 |  | **Video 1/2 Select Output**<br>High output level indicates that Video 1 is selected to be the main picture video. Low output level indicates Video 2 is selected to be the main picture video. |
| 28 |  | **Sync Out**<br>Outputs the video signal selected as the PIP to be filtered and applied to the H and V timebase through the Sync In pin. |
| 29 |  | **Sync In**<br>PIP sync pulses are externally filtered and applied to the H and V timebase to allow H and V synchronization. |
| 30 |  | **Multi Test**<br>Under control of $I^2C$ bus output signals for test and adjustment are provided through this pin. |
| 31 |  | **H PLL**<br>Connection for horizontal timebase PLL filter. |

9

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 33 |  | **Filter PLL**<br>The on board reference filter produces a phase shift which is measured and applied to an internal filter PLL. This capacitor connected to this pin stores the phase correction voltage for the PLL which sets the 90° phase correction reference for the rest of the on chip filters. |
| 36 and 34 |  | **Video Input 1 and 2**<br>Accepts ac coupled 1.0 Vpp composite video input usually from a source generated inside the TV and an external video source.<br>The series coupling capacitor also functions as the storage capacitor for the clamp voltage for the input circuit. It is necessary to return the input of this capacitor to ground through a dc low impedance to enable this clamp function. R = 50 to 100 Ω is acceptable. |
| 37 |  | **Decoder ACC**<br>The Decoder ACC pin provides access to the internal chroma decoder automatic gain control amplifier. The ACC capacitor filters the feedback loop of this amplifier.<br>During PIP burst gate time a voltage proportional to the burst gate magnitude is stored on the capacitor connected to this pin to compensate for input chroma level variation and provide a constant U and V output level to the A/D conversion stage. |
| 38 |  | **Decoder Crystal**<br>4X Sub–Carrier crystal used to synchronize the decoding of the PIP UV information prior to A/D conversion, sub–sampling and storage in the field memory.<br>The crystal frequency is 14.31818 MHz. |
| 39 |  | **Decoder PLL**<br>Connection for Decoder PLL filter. |

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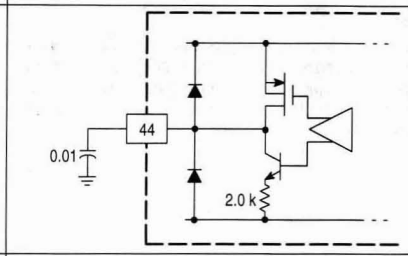
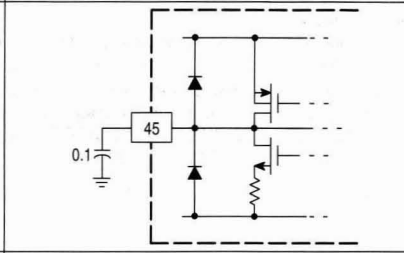
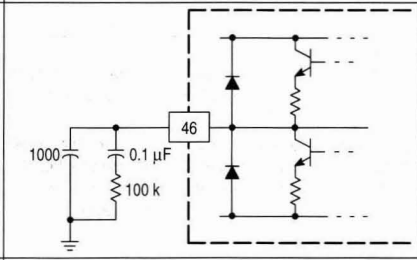
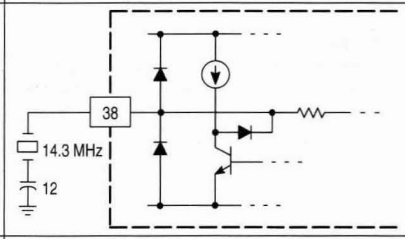
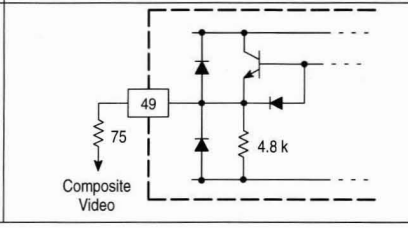
PIN FUNCTION DESCRIPTION (continued)

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 44 |  | **Encoder Phase**<br>Phase difference of the main to encoded burst is sampled and applied to the capacitor connected to this pin to shift the phase of the re–encoded chrominance to match the main. |
| 45 |  | **Encoder ACC**<br>The Encoder ACC pin provides access to the internal chroma reference sample and hold circuit, which stores the sampled value of the main channel chroma burst amplitude on this external ACC capacitor. The ACC amplifier matches the chroma amplitude of the insert picture to that of the main picture. |
| 46 |  | **Encoder PLL**<br>Connection for Encoder PLL filter. See separate discussion for filter values. |
| 47 |  | **Encoder Crystal**<br>4X Sub–Carrier crystal used to synchronize the encoding of the PIP YUV from the field memory with the main video. The output from this PLL is phase corrected to match the PIP video signal to the main video at the PIP switch.<br>The crystal frequency is 14.31818 MHz. |
| 49 |  | **Video Out**<br>The selected Video 1/2 input is available at the Video Out mixed with the PIP overlay when selected. This signal is a nominal 2.0 V peak–to–peak signal unterminated. This connection is intended to drive an external series 75 Ω load into a 75 Ω termination to ground to provide a 1.0 Vpp signal at the termination. |

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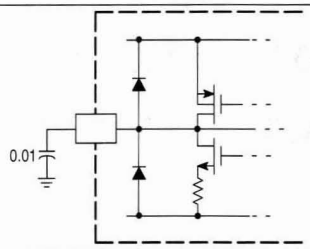
**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Equivalent Internal Circuit | Description |
|---|---|---|
| 54, 53, 52, 42, 41, 40 |  | **Encoder and Decoder YUV Caps** During the internal H rate clamping time the YUV reference levels are set by the charge on the capacitors attached to these pins. The nominal value of these capacitors should be 0.01 µF. |

## SOFTWARE CONTROL OF THE MC44461

Communications to and from the MC44461 follows the $I^2C$ interface protocol defined by the Philips Corporation. In simple terms, the $I^2C$ is a two line, multi–master, bidirectional bus used for data transfer. Although an $I^2C$ system can be multi–master, the MC44461 never functions as a master.

The MC44461 has a write address of $24 and a flag read address of $25. A block diagram of the $I^2C$ interface is shown in Figure 3. Writing to the MC44461 registers can cause momentary jitter or other undesirable effects to the TV screen, writing should be done only during the vertical retrace (before line 20).

### Write to Control Registers

A write cycle consists of three bytes, with three acknowledge bits.

1) The first byte is always the write address for the MC44461 ($24).

2) The second byte defines the sub–address register, within the MC44461, to be updated; $00 through $0B.

3) The third byte is the data for that register.

The communication begins when a start sequence (data line taken low while the clock line is high) is initiated by the master (MCU) and detected by the MC44461, generating an internal reset. The first byte is then generated, and if the address is correct ($24), an acknowledge is generated by the MC44461, which tells the master to continue to send data. The second byte is then entered, followed by an acknowledge. The third byte is the operative data which is stored in the designated register, followed by the third acknowledge. Writing to multiple registers in a single write operation is permitted in the MC44461. The sub–address is auto–incremented while receiving n – data bytes + Ack, ending with the stop sequence. The sub–address of the 11 registers are at $00 through $0B.

**Figure 3. $I^2C$ Bus Interface and Decoder**

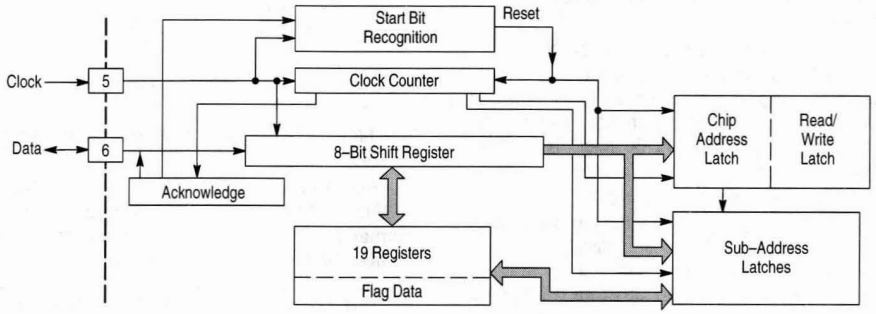
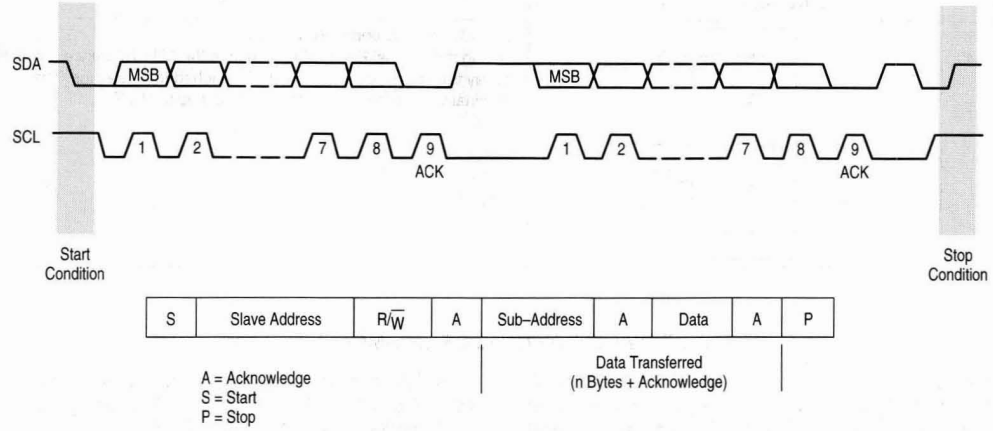


**Figure 4. I²C Data Transfer**




## I²C REGISTER DESCRIPTIONS

Base write address = 24h

Base read address = 25h

### Read Register

There are two active bits in the single read byte available from the MC44461 as follows:

*Write Vertical Indicator (WVI0) – D7*

When 0 indicates that the write operation specified by the last I²C command has been completed.

*PIP Sync Detect Bit (PSD0) – D1*

When 0 indicates that the PIP video H pulses are present and the horizontal timebase oscillator is within acceptable limits.

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### Write Registers

**Read Start Position/Write Start Position Registers**

Sub–address = 00h

*Write Raster Position Start Bits (WPS0–2) – D0–D2*

Establishes the horizontal beginning of the PIP and its black level measurement gate. This beginning may be varied by approximately 3.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

*Read Raster Position Bits (RPS0–3) – D4–D7*

Establishes the clamp gate position for the black level reference for the main picture. This position may be varied by approximately 5.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

**Pip Switch Delay/Vertical Filter Register**

Sub–address = 01h

*PIP Switch Delay Bits (PSD0–3) – D0–D3*

Delays the start of PIP on time relative to the PIP picture. These bits are used to center the PIP border and PIP picture in the horizontal direction.

*Vertical Filter Bit (VFON) – D4*

When the filter is activated (VFON = 1) a three line weighted average is taken to provide the data stored in the field memory.

**Border Color Register**

Sub–address = 02h

*Border Color Bits (BC0–2) – D0–D2*

These Bits control the color of the border. Note that when using one of the saturated border colors it is possible to get objectionable dot crawl at the edge of the border in some TVs unless appropriate comb filtering is used in the TV circuitry.

| BC (2:0) | Border Color |
|---|---|
| 000 | Black |
| 001 | White 70% |
| 010 | No Border (clear) |
| 011 | No Border (clear) |
| 100 | Blue |
| 101 | Green |
| 110 | Red |
| 111 | White |

**Test Mode/Main Vertical and Horizontal Polarity Register**

Sub–address = 03h

*Internal Test Mode Register (ITM0–2) – D0–D2*

Sets the Multi Test Pin output to provide one of several internal signals for test and production alignment. Also controls the test memory address counter.

| ITM (2:0) | Multi–Test I/O and Function |
|---|---|
| 000 | Input – Analog Test mode |
| 001 | Input – Digital Test mode |
| 010 | Output – Sync Detect |
| 011 | Output – PIP Switch |
| 100 | Output – PIP H Detect |
| 101 | Output – PIP V Detect |
| 110 | Output – PIP Clamp |
| 111 | Output – Main Clamp |

*Main vertical polarity select bit (MVP0) – D6*

Selects polarity of active level of vertical reference input. 0 = positive going, 1 = negative going.

*Main horizontal polarity select bit (MHP0) – D7*

Selects polarity of active level of horizontal reference input. 0 = positive going, 1 = negative going.

**PIP Freeze/PIP Size/Main and PIP Video Source Register**

Sub–address = 04h

*PIP Freeze Bit (STIL0) – D4*

When set to one, the most recently received field is continuously displayed until the freeze bit is cleared.

*PIP Size Bit (PSI90) – D5*

Switches the PIP size between 1/16 main size (when 0) and 1/9 main size (when 1).

*Main Video Source Select Bit (MSEL0) – D6*

Selects which video input will be applied to the PIP switch as the main video out.

*PIP Video Source Select Bit (PSEL0) – D7*

Selects which video input will be applied to the video decoder to provide the PIP video.

| MSEL/PSEL | Function |
|---|---|
| 0 | Video 1 Input to Main/<br>Video 1 Input to PIP |
| 1 | Video 2 Input to Main/<br>Video 2 Input to PIP |

**PIP On/PIP Blank Register**

Sub–address = 05h

*PIP On Bit (PON0) – D0*

When on (1) turns the PIP on.

*PIP Blanking Bit (PBL0) – D4*

When on (1) sets the PIP to black. If the PIP is off, then it will be black if it is turned on. Overrides all other settings of the PIP control.

**PIP X Position Register**

Sub–address = 06h

*X Position Bits (XPS0–5) – D0–D5*

Moves the PIP start position from the left to the right edge of the display in 64 steps. There is protection circuitry to prevent the PIP from interfering with the main picture sync pulses.

**PIP Y Position Register**

Sub–address = 07h

*Y Position Bits (YPS0–5) – D0–D5*

Moves the PIP start position from the top to the bottom edge of the display in 64 steps. There is protection circuitry to prevent the PIP from interfering with the main picture sync pulses.

**PIP Chroma Level Register**

Sub–address = 08h

*Chroma (C0–5) – D0–D5*

The color of the PIP can be adjusted to suit viewer preference by setting the value stored in these bits. A total of 64 steps varies the color from no color to maximum. This control acts in conjunction with the auto phase control.

**PIP Tint Level Register**

Sub–address = 09h

*Tint (T0–5) – D0–D5*

An auto phase control compares the main color burst to the internally generated pseudo color burst so that the tints are matched. In addition to this, the tint of the PIP can be varied ±10° in a total of 64 steps by changing the value of these bits to suit viewer preference.

**PIP Luma Delay Register**

Sub–address = 0Ah

*Y Delay (YDL0–2) – D0–D2*

Since the Chroma passes through a bandpass filter and the color decoder, it is delayed with respect to the Luma signal. Therefore, to time match the Luma and Chroma these bits are set to a single value determined to be correct in the application.

**Pip Fill/Test Register**

Sub–address = 0Ch

*PIP Fill Bits (PIPFILL0–1) – D0–D1*

May be used to fill the PIP with one of three selectable solid colors

*Test Register Bits (INTC0 and MACR0) – D6–D7*

Used for production test only.

**Function Control of the MC44461**

The registers of the MC44461 may be programmed via the $I^2C$ bus. At power up, the registers are in an undefined state. The Setup Value given in the Register Table represents a nominal start point. The setup will put a 1/9 size PIP, with white borders, in the lower right corner of the screen.

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## I²C REGISTER TABLE

| Sub–address | Setup Values | Data Bit D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---|---|---|---|---|---|---|---|---|---|
| 00h | 45h | RPS3 | RPS2 | RPS1 | RPS0 | – | WPS2 | WPS1 | WPS0 |
| 01h | 1Ah | – | – | – | VFON | PSD3 | PSD2 | PSD1 | PSD0 |
| 02h | 07h | – | – | – | – | – | BC2 | BC1 | BC0 |
| 03h | 02h | MHP0 | MVP0 | – | – | – | ITM2 | ITM1 | ITM0 |
| 04h | 20h | PSEL0 | MSEL0 | PSI90 | STIL0 | – | – | – | – |
| 05h | 01h | – | – | – | PBL0 | – | – | – | PON0 |
| 06h | 34h | – | – | XPS5 | XPS4 | XPS3 | XPS2 | XPS1 | XPS0 |
| 07h | 24h | – | – | YPS5 | YPS4 | YPS3 | YPS2 | YPS1 | YPS0 |
| 08h | 20h | – | – | C5 | C4 | C3 | C2 | C1 | C0 |
| 09h | 20h | – | – | T5 | T4 | T3 | T2 | T1 | T0 |
| 0Ah | 02h | – | – | – | – | – | YDL2 | YDL1 | YDL0 |
| 0Bh | – | – | – | – | – | – | – | – | – |
| 0Ch | 00h | – | – | – | – | – | – | – | – |

## CIRCUIT DESCRIPTION

The MC44461 Picture–in–Picture (PIP) controller is composed of an analog section, logic section and an 8192 x 8–bit DRAM array. A block diagram showing details of all of these sections is shown in the Representative Block Diagram.

The analog section includes an Input Switch, Sync Processor, Filters, PLLs, NTSC Decoder, ADC, DACs, NTSC Encoder and Output Switch. All necessary controls are provided by registers in the logic section. These registers are set by external control through the I²C Bus.

In operation, the MC44461 overlays a single PIP on the main video in either a 1/9th or 1/16th size. In 1/9th, the PIP is 152 samples (114 Y, 19 V, 19 U) by 70 lines and occupies 8094 bytes of the 8192 byte DRAM. The 1/16 size is 112 samples (84 Y, 14 V, 14 U) by 52 lines and occupies 4452 bytes of the DRAM. An extra line of data is stored for each PIP size to allow for interlace disorder correction. The 6:1:1 samples are formatted by the logic section as follows in order to efficiently utilize memory:

Byte 1: Y0(5:0), V(1:0)

Byte 2: Y1(5:0), V(3:2)

Byte 3: Y2(5:0), V(5:4)

Byte 4: Y3(5:0), U(1:0)

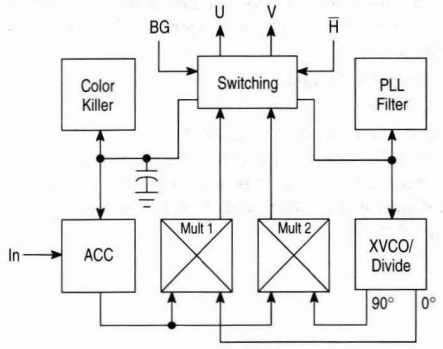
Byte 5: Y4(5:0), U(3:2)

Byte 6: Y5(5:0), U(5:4)

Refer to the block diagram. Both the video inputs are applied to an input switch which is controlled by the I²C bus interface. Either of the inputs is applied to the PIP processing circuitry and either to the main video signal path of the output switch. The signal applied to the PIP processor also provides the vertical sync reference to the PIP processor.

The PIP output from the switch is applied to a 1.0 MHz cutoff low pass GmC biquad filter to extract the luminance signal and a similar bandpass filter to pass chroma to the decoder section. These filters are tracked to a master GmC cell using subcarrier as a reference. A single–ended transconductance stage with relatively large signal handling ability (>2.5 Vpp @ 4.5 V $V_{CC}$) is used to avoid potential noise problems.

**Figure 5. NTSC Decoder**




The NTSC Decoder (Figure 5) consists of two multipliers, a voltage controlled 4 X S/C crystal oscillator/divider, Automatic Color Control (ACC) block, Color Kill circuit and necessary switching. During Burst Gate time, the ACC block in the NTSC Decoder is calibrated with respect to burst magnitude by applying the output of multiplier 1 to the reference input of the ACC block. The result is U and V outputs which are 0.6 V ± 0.5 dB for burst amplitudes varying from –12 dB to 3.0 dB. The second multiplier serves as a phase detector during color burst to match the 90 degree output from the XVCO to the 180 degree color burst and feed

a correction current to the PLL filter. The phase is correct when the two signals are 90 degrees out of phase.

During the H drive time, the output of the multipliers is fed to the YUV clamp, filtered to 200 KHz and input along with the Y signal to the multiplexer.

The YUV samples are fed through a multiplexer to a single six bit A/D converter. The A/D is a flash type architecture and is capable of digitizing at a 20 MHz sample rate. It is comprised of an internal bandgap source voltage reference, a 64 tap resistor ladder comparator array, a binary encoder and output latches. Once the multiplexer has switched, sufficient time is provided to allow the A/D converter to settle before the reading is latched. The encoder code is determined from the values of any comparators which are not metastable.

The multiplexer and A/D converter receive and convert the YUV data at a $4F_{SC}/3$ rate for a 1/9th size picture or $F_{SC}$ for a 1/16th size picture. The samples are taken in the following way to simplify the control logic:

Y,V,Y,U,Y,V,Y,U

To provide a 6:1:1 format, one of three U and V samples is saved to memory giving a luminance sample rate of $2F_{SC}/3$ for a 1/9th picture and $F_{SC}/2$ for a 1/16 picture. In the vertical direction, one line of every 3 (1/9th picture) or 4 (1/16th picture) are saved. In order to avoid objectionable artifacts, a piece–wise vertical filter is used to take a weighted average on the luminance samples. For three lines (1/9th size) the weight is 1/4 + 1/2 + 1/4 and for four lines (1/16 size) it is 1/4 + 1/4 + 1/4 + 1/4. This filter also delays the luma samples correcting for the longer chroma signal path through the decoder.

Finally the logic incorporates a field generator to determine the current field in order to correct interlace disorders arising from a single field memory.

A separate process runs in the logic section to create the PIP window on the main picture. Control signals are generated and sent to the memory controller to read data from the field memory. Data from the eight bit memory are then de–multiplexed into a six bit YUV format, borders are added, blanking is generated for the video clamps and sent to the Y, U and V DACs. Since the PIP display is based on a data clock, it is important to minimize the main display clock skew on a line by line basis. Skew is minimized in the MC44461 by reclocking the display timebase to the nearest rising or falling edge of a $16F_{SC}$ clock. This produces a maximum line to line skew of approximately 8.0 ns which is not perceptible to the viewer. The PIP write logic also incorporates a field generator for use by the memory controller for interlace disorder correction. Interlace disorder can occur when the line order of the two fields of the PIP image is swapped due to a mismatch with the main picture field or due to an incomplete field being displayed from memory. The main and PIP field generators, along with monitoring, when the PIP read address passes the PIP write address, allows the read address to the memory to be modified to correct for interlace disorder.

The read logic can provide various border colors: black, 75% white (light gray), 50% white (medium gray), red, green, blue or transparent (no border). In a system without an adaptive comb filter, borders which contain no chroma give the best results. Also built into the read logic is a PIP fill mode which allows the PIP window to be filled with either a solid green, blue or red color as an aid in aligning the PIP analog color circuitry.

Because the DAC output video will be referenced during back porch time, the read processor zeroes the luminance value and sets the bipolar U and V values to mid–range during periods outside the PIP window to ensure clamping at correct levels. Since the PIP window is positioned relative to the main picture's vertical and horizontal sync, a safety feature turns off the window if the window encroaches upon the sync period, thus preventing erroneous clamping.

The Y, U and V DACs are all three of the same design. A binary weighted current source is used, split into two, three bit levels. In the three most significant bits, the current sources are cascaded to improve the matching to the three least significant current sources. Analog transmission gates, switched by the bi–phase outputs of the data latches, feed the binary currents to the single ended current mirror. The output current is subsequently clamped and filtered for processing buy the NTSC Encoder.

The outputs of the U and V DACS are buffered and burst flag pulses added to both signals. The U burst flag is fixed to generate a –180° color burst at the modulator output. The V burst flag is variable under the control of an internal register set through the $I^2C$ bus to provide a variable tint. Saturation is controlled by varying a register which sets the reference voltage to the U and V DACs. This is also under $I^2C$ bus control. By oversampling the U and V DACs, it was possible to use identical post–DAC filtering for Y, U and V, thereby reducing the delay inequalities between Y and UV and also simplifying the design. After filtering, the U and V signals are clamped to an internal reference voltage during horizontal blanking periods and fed to the U and V modulators. In the NTSC Decoder, the Y, U and V signals were scaled to use the entire A/D range. Gain through the NTSC Encoder is set to properly match these amplitudes.

The phase of the re–encoded chrominance must match that of the incoming main video signal at the input to the PIP switch, so a separate first order PLL is placed within the loop of the main video signal burst PLL. The first order PLL compares the phase of the main burst with that of the encoded burst and moves the oscillator phase so that they match. A special phase shift circuit allowing a continuous range of 180° was developed to do this.

The amplitude of the re–encoded chrominance signal must also match that of the main video signal. To do this, a synchronous amplitude comparator looks at both burst signals and adjusts the chrominance amplitude in the modulator section of the NTSC encoder. The Y signal from the YDAC is compared to the main video signal at black level during back porch time and clamped to this same black level voltage. The PIP chrominance and luminance are then added together and fed to the PIP output switch through a buffered output.

MOTOROLA

*Product Preview*

# Y-C Picture-in-Picture (PIP) Controller

**MC44462**

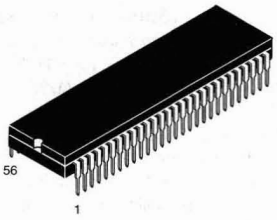
**Y–C PICTURE–IN–PICTURE (PIP) CONTROLLER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC44462 Y–C PIP controller is a low cost member of a family of high performance PIP controllers and video signal processors for television. It is a follow–up to the MC44461 PIP and has a modified input selection to allow higher performance in TV systems which have S–Video inputs on the back panel. The S–Video input is separate luma (luminance) and chroma components. It is NTSC compatible and contains all the analog signal processing, control logic and memory necessary to provide for the overlay of a small picture from a second non synchronized source onto the main picture of a television. All control and setup of the MC44462 is via a standard two pin $I^2C$ bus interface. The device is fabricated using BICMOS technology. It is available in a 56–pin shrink dip (SDIP) package.

The main features of the MC44462 are:

- Switchable PIP Composite Video Signals – Video 1 and Video 2
- S–Video Output Allows High Performance in TV
- Two PIP Sizes; 1/16 and 1/9 Screen Area
- Freeze Field Feature
- Variable PIP Position in 64–X by 64–Y Steps
- PIP Border with Programmable Color
- Programmable PIP Tint and Saturation Control
- Automatic Main to PIP Contrast Balance
- Vertical Filter
- Integrated 64 k Bit DRAM Memory Resulting in Minimal RFI
- Minimal RFI Allows Simple Low Cost Application into TV
- $I^2C$ Bus Control – No External Variable Adjustments Needed
- Operates from a Single 5.0 V Supply
- Economical 56–Pin Shrink DIP Package

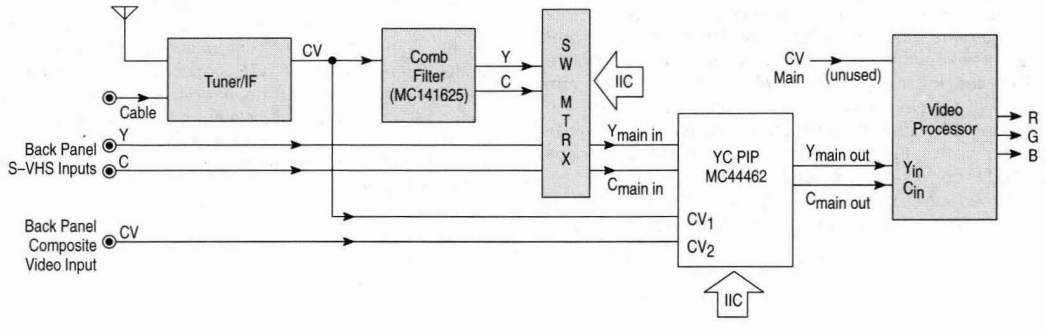



**B SUFFIX**
PLASTIC PACKAGE
CASE 859
(SDIP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44462B | $T_J$ = –65° to +150°C | SDIP |

**YC–PIP System Diagram**

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## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{DD}$ | –0.5 to +6.0 | V |
| Power Supply Voltage | $V_{CC}$ | –0.5 to +6.0 | V |
| Input Voltage Range | $V_{IR}$ | –0.5, $V_{DD}$ + 0.5 | V |
| Output Current | $I_O$ | 160 | mA |
| Power Dissipation<br>Maximum Power Dissipation @ 70°C<br>Thermal Resistance, Junction–to–Air | <br>$P_D$<br>$R_{\theta JA}$ | <br>1.3<br>59 | <br>W<br>°C/W |
| Junction Temperature (Storage and Operating) | $T_J$ | –65 to +150 | °C |

**NOTE:** ESD data available upon request.

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | |
| Total Supply (Pins 8, 15, 43 and 50) | Total $I_{Supply}$ | – | 100 | 160 | mA |
| **VIDEO** | | | | | |
| Composite Video Input (Pin 34 or 36) | CVi | – | 1.0 | – | Vpp |
| Luma Output (Pin 49, Unterminated) | – | – | 2.0 | – | Vpp |
| Video Output DC Level (Sync Tip) | – | – | 1.0 | – | Vdc |
| Video Gain | – | – | 6.0 | – | dB |
| Video Frequency Response (Main Video to –1.0 dB) | – | – | 10 | – | MHz |
| Color Bar Accuracy | – | – | ±4.0 | – | deg |
| Video Crosstalk (@ 75% Color Bars)<br>Main to PIP<br>PIP to Main | – | <br>–<br>– | <br>55<br>55 | <br>–<br>– | dB |
| Output Impedance | – | – | 5.0 | – | Ω |
| **HORIZONTAL TIMEBASE** | | | | | |
| Free Run HPLL Frequency (Pin 16) | – | – | 15734 | – | Hz |
| HPLL Pull–In Range | – | – | ±400 | – | Hz |
| HPLL Jitter | – | – | ±4.0 | – | ns |
| Burst Gate Timing (from Trailing Edge Hsync, Pin 24) | – | – | 1.0 | – | µs |
| Burst Gate Width | – | – | 4.0 | – | µs |
| **VERTICAL TIMEBASE** | | | | | |
| Vertical Countdown Window | – | – | 232 – 296 | – | H lines |
| Vertical Sync Integration Time | – | – | 31 | – | µs |
| **ANALOG TO DIGITAL CONVERTER** | | | | | |
| Resolution | – | – | 6 | – | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| ADC – Y Frequency Response @ –5.0 dB | – | – | 1.0 | – | MHz |
| ADC – U, V Frequency Response @ –5.0 dB | – | – | 200 | – | kHz |
| Sample Clock Frequency (4/3 $F_{SC}$) | – | – | 4.773 | – | MHz |

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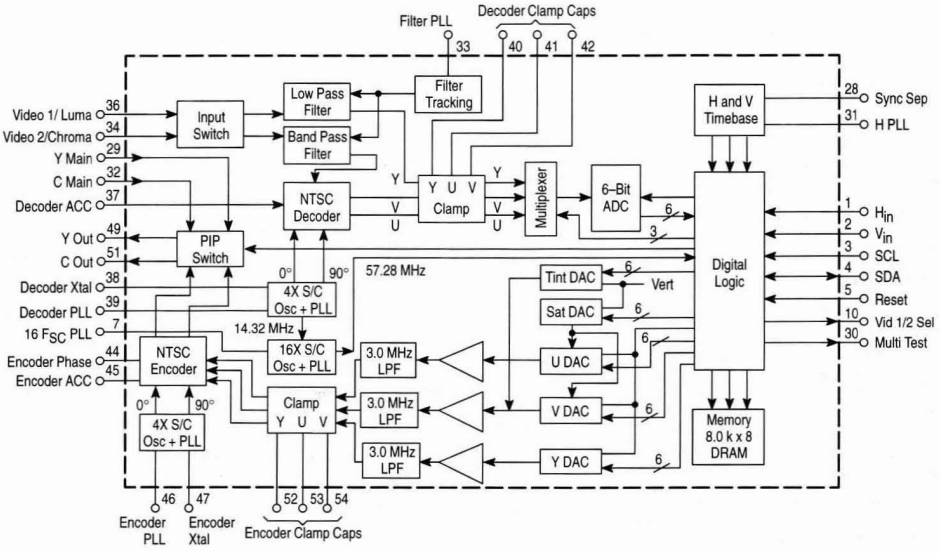
**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

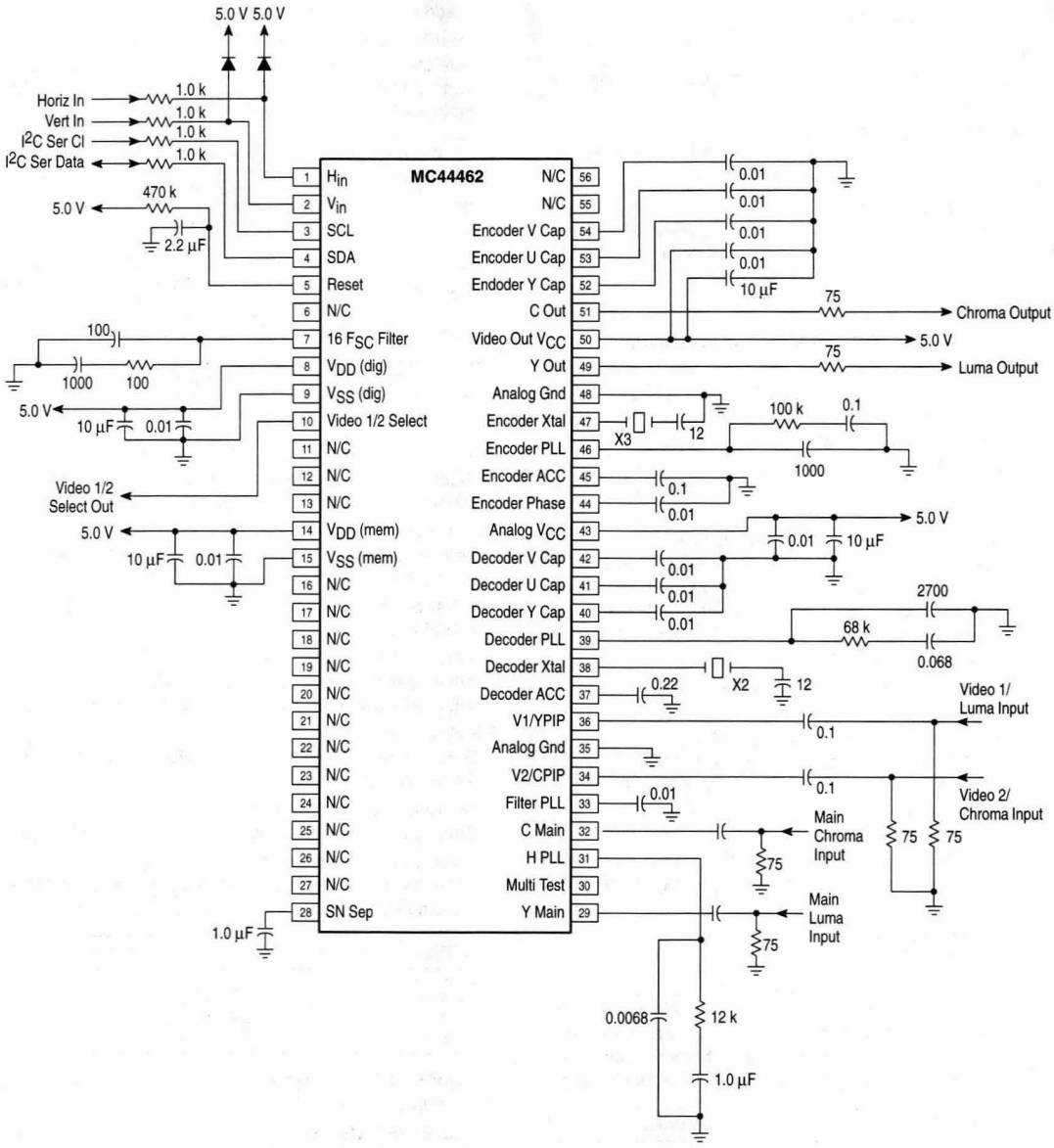
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DIGITAL TO ANALOG CONVERTER** | | | | | |
| Resolution | – | – | – | 6 | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| Tint DAC Control Range (in 64 Steps) | – | – | ±10 | – | Deg |
| Saturation DAC Control Range (in 64 steps) | – | – | ±6.0 | – | dB |
| **NTSC DECODER** | | | | | |
| Color Kill Threshold | – | – | –24/–16 | – | dB |
| Threshold Hysteresis | – | – | ±1.0 | – | dB |
| ACC (Chroma Amplitude Change, +3.0 dB to –12 dB) | – | – | ±0.5 | – | dB |
| **PIP CHARACTERISTICS** | | | | | |
| PIP Size | – | | | | |
| 1/9 Screen Horizontal | | – | 114 | – | pels |
| 1/9 Screen Vertical | | – | 71 | – | lines |
| 1/16 Screen Horizontal | | – | 84 | – | pels |
| 1/16 Screen Vertical | | – | 53 | – | lines |
| Border Size Horizontal | – | – | 3 | – | pels |
| Border Size Vertical | – | – | 2 | – | lines |
| Output PEL Clock (4 $F_{SC}$) | – | – | 14.318 | – | MHz |
| Position Control Range Horizontal (% of Main Picture), 64 Steps | – | – | 100 | – | % |
| Position Control Range Vertical (% of Main Picture), 64 Steps | – | – | 100 | – | % |

**Figure 1. Representative Block Diagram**




This device contains approximately 500,000 active transistors.

**Figure 2. Application Circuit**




X2 – 14.31818 MHz – Fox 143–20 or equivalent
X3 – 14.31818 MHz – Fox 143–20 or equivalent

**NOTE:** For proper noise isolation, Power Supply Pins 8, 14, 43 and 50 should be bypassed by both high and low frequency capacitors. As a guideline, a 10 µF in parallel with a 0.1 µF at each supply pin is recommended.

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## I²C REGISTER DESCRIPTIONS

Base write address = 24h

Base read address = 25h

**Read Register**

There are two active bits in the single read byte available from the MC44462 as follows:

*Write Vertical Indicator (WVI0) – D7*

When 0 indicates that the write operation specified by the last I²C command has been completed.

*PIP Sync Detect Bit (PSD0) – D1*

When 0 indicates that the PIP video H pulses are present and the horizontal timebase oscillator is within acceptable limits.

**Write Registers**

**Read Start Position/Write Start Position Registers**
Sub–address = 00h

*Write Raster Position Start Bits (WPS0–2) – D0–D2*

Establishes the horizontal beginning of the PIP and its black level measurement gate. This beginning may be varied by approximately 3.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

*Read Raster Position Bits (RPS0–3) – D4–D7*

Establishes the clamp gate position for the black level reference for the main picture. This position may be varied by approximately 5.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

**Pip Switch Delay/Vertical Filter Register**
Sub–address = 01h

*PIP Switch Delay Bits (PSD0–3) – D0–D3*

Delays the start of PIP on time relative to the PIP picture. These bits are used to center the PIP border and PIP picture in the horizontal direction.

*Vertical Filter Bit (VFON) – D4*

When the filter is activated (VFON = 1) a three line weighted average is taken to provide the data stored in the field memory.

**Border Color Register**
Sub–address = 02h

*Border Color Bits (BC0–2) – D0–D2*

These Bits control the color of the border. Note that when using one of the saturated border colors it is possible to get objectionable dot crawl at the edge of the border in some TVs unless appropriate comb filtering is used in the TV circuitry.

| BC (2:0) | Border Color |
|---|---|
| 000 | Black |
| 001 | White 70% |
| 010 | No Border (clear) |
| 011 | No Border (clear) |
| 100 | Blue |
| 101 | Green |
| 110 | Red |
| 111 | White |

**Test Mode/Main Vertical and Horizontal Polarity Register**
Sub–address = 03h

*Internal Test Mode Register (ITM0–2) – D0–D2*

Sets the Multi Test Pin output to provide one of several internal signals for test and production alignment. Also controls the test memory address counter.

| ITM (2:0) | Multi–Test I/O and Function |
|---|---|
| 000 | Input – Analog Test mode |
| 001 | Input – Digital Test mode |
| 010 | Output – Sync Detect |
| 011 | Output – PIP Switch |
| 100 | Output – PIP H Detect |
| 101 | Output – PIP V Detect |
| 110 | Output – PIP Clamp |
| 111 | Output – Main Clamp |

*Main vertical polarity select bit (MVP0) – D6*

Selects polarity of active level of vertical reference input. 0 = positive going, 1 = negative going.

*Main horizontal polarity select bit (MHP0) – D7*

Selects polarity of active level of horizontal reference input. 0 = positive going, 1 = negative going.

**PIP Freeze/PIP Size/Main and PIP Video Source Register**
Sub–address = 04h

*PIP Freeze Bit (STIL0) – D4*

When set to one, the most recently received field is continuously displayed until the freeze bit is cleared.

*PIP Size Bit (PSI90) – D5*

Switches the PIP size between 1/16 main size (when 0) and 1/9 main size (when 1).

*Video Type Select Bit (YCPSEL) – D6*

Selects which video type will be applied to the PIP input.

*PIP Video Source Select Bit (PSEL0) – D7*

Selects which composite video input will be applied to the video decoder to provide the PIP video in CV mode.

| PSEL | YCPSEL | Function |
|---|---|---|
| 0 | 1 | YC Input to PIP |
| 0<br>1 | 0 | $CV_1$ Input to PIP<br>$CV_2$ Input to PIP |

**PIP On/PIP Blank Register**
Sub–address = 05h

*PIP On Bit (PON0) – D0*

When on (1) turns the PIP on.

*PIP Blanking Bit (PBL0) – D4*

When on (1) sets the PIP to black. If the PIP is off, then it will be black if it is turned on. Overrides all other settings of the PIP control.

**PIP X Position Register**
Sub–address = 06h

*X Position Bits (XPS0–5) – D0–D5*

Moves the PIP start position from the left to the right edge of the display in 64 steps. There is protection circuitry

to prevent the PIP from interfering with the main picture sync pulses.

**PIP Y Position Register**
Sub–address = 07h

*Y Position Bits (YPS0–5) – D0–D5*
Moves the PIP start position from the top to the bottom edge of the display in 64 steps. There is protection circuitry to prevent the PIP from interfering with the main picture sync pulses.

**PIP Chroma Level Register**
Sub–address = 08h

*Chroma (C0–5) – D0–D5*
The color of the PIP can be adjusted to suit viewer preference by setting the value stored in these bits. A total of 64 steps varies the color from no color to maximum. This control acts in conjunction with the auto phase control.

**PIP Tint Level Register**
Sub–address = 09h

*Tint (T0–5) – D0–D5*
An auto phase control compares the main color burst to the internally generated pseudo color burst so that the tints are matched. In addition to this, the tint of the PIP can be varied ±10° in a total of 64 steps by changing the value of these bits to suit viewer preference.

**PIP Luma Delay Register**
Sub–address = 0Ah

*Y Delay (YDL0–2) – D0–D2*
Since the Chroma passes through a bandpass filter and the color decoder, it is delayed with respect to the Luma signal. Therefore, to time match the Luma and Chroma these bits are set to a single value determined to be correct in the application.

**Pip Fill/Test Register**
Sub–address = 0Ch

*PIP Fill Bits (PIPFILL0–1) – D0–D1*
May be used to fill the PIP with one of three selectable solid colors

*Test Register Bits (INTC0 and MACR0) – D6–D7*
Used for production test only.

**I²C REGISTER TABLE**

| Sub–address | Data Bit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| 00 | RPS3 | RPS2 | RPS1 | RPS0 | – | WPS2 | WPS1 | WPS0 |
| 01 | – | – | – | VFON | PSD3 | PSD2 | PSD1 | PSD0 |
| 02 | – | – | – | – | – | BC2 | BC1 | BC0 |
| 03 | MHP0 | MVP0 | – | – | – | ITM2 | ITM1 | ITM0 |
| 04 | PSEL0 | YCPSEL | PSI90 | STIL0 | – | – | – | – |
| 05 | – | – | – | PBL0 | – | – | – | PON0 |
| 06 | – | – | XPS5 | XPS4 | XPS3 | XPS2 | XPS1 | XPS0 |
| 07 | – | – | YPS5 | YPS4 | YPS3 | YPS2 | YPS1 | YPS0 |
| 08 | – | – | C5 | C4 | C3 | C2 | C1 | C0 |
| 09 | – | – | T5 | T4 | T3 | T2 | T1 | T0 |
| 0A | – | – | – | – | – | YDL2 | YDL1 | YDL0 |
| 0B | – | – | – | – | – | – | – | – |
| 0C | – | – | – | – | – | – | – | – |

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MOTOROLA

*Product Preview*

# Picture-in-Picture (PIP) Controller

**MC44463**

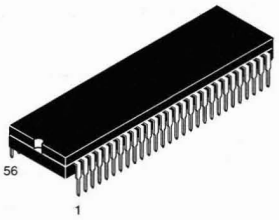
**REPLAY AND MULTIPLE PICTURE–IN–PICTURE (PIP) CONTROLLER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC44463 Picture–In–Picture (PIP) controller is a low cost member of a family of high performance PIP controllers and video processors for television. It is a follow–up to the MC44461 PIP, in which two additional modes of operation have been added. A replay mode is provided, which captures several seconds of the main picture for replay in four different speeds. The capture time is programmable in four resolutions (ratio of captured fields to total fields), which trade the number of fields captured to the length of replay time. The second additional mode provides for multiple small picture overlays from a second non–synchronized source. The number of PIP images is 3 for the 1/9 screen area and 4 for the 1/16 screen area. Like the MC44461 this is NTSC compatible, $I^2C$ bus controlled and available in the 56–pin shrink dip (SDIP) package.

The main features of the MC44463 are:

- Three PIP Functional Modes: Standard Single Active PIP Mode, Up to 8 Seconds of Capture and Replay Mode, and a 3 or 4 Multiple PIP Mode – Vertical Stacked with 1 Active at Any One Time
- 4 Capture Resolutions – 1 out of 10, 1:8, 1:6, 1:4. 4 Playback Speeds = 1 Times Acquire Speed; 1/2; 1/4; 1/8
- Full 2 Frame Store for the Single PIP Removes the Rolling Store/Playback Memory Interference – "Joint Line"
- External Memory for Replay and Multiple Modes: 4 Meg and 16 Meg
- Two NTSC CVBS Inputs – Switchable Main and PIP Video Signals
- Single NTSC CVBS Output Allows Simple TV Chassis Integration
- Two PIP Sizes; 1/16 and 1/9 Screen Area – Freeze Field Feature
- Variable PIP Position in 64–X by 64–Y Steps
- PIP Border with Programmable Color
- Programmable PIP Tint and Saturation Control
- Automatic Main to PIP Contrast Balance
- Vertical Filter
- $I^2C$ Bus Control – No External Variable Adjustments Needed
- Operates from a Single 5.0 V Supply
- Economical 56–Pin Shrink DIP Package

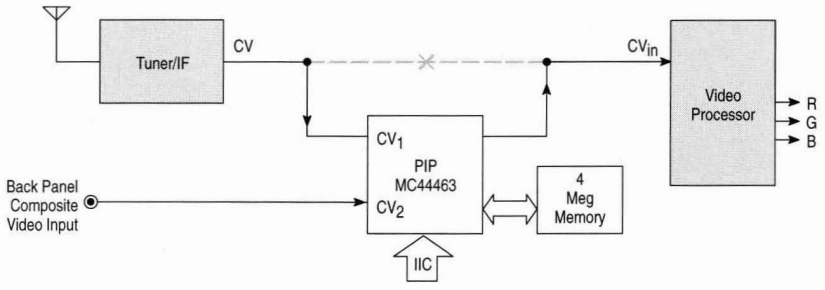



**B SUFFIX**
PLASTIC PACKAGE
CASE 859
(SDIP)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44463B | $T_J$ = –65° to +150°C | SDIP |

**Composite Video Simplified System Diagram**

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## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{DD}$ | –0.5 to +6.0 | V |
| Power Supply Voltage | $V_{CC}$ | –0.5 to +6.0 | V |
| Input Voltage Range | $V_{IR}$ | –0.5, $V_{DD}$ + 0.5 | V |
| Output Current | $I_O$ | 160 | mA |
| Power Dissipation<br>Maximum Power Dissipation @ 70°C<br>Thermal Resistance, Junction–to–Air | <br>$P_D$<br>$R_{\theta JA}$ | <br>1.3<br>59 | <br>W<br>°C/W |
| Junction Temperature (Storage and Operating) | $T_J$ | –65 to +150 | °C |

**NOTE:** ESD data available upon request.

## ELECTRICAL CHARACTERISTICS ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | |
| Total Supply (Pins 8, 15, 43 and 50) | Total $I_{Supply}$ | – | 110 | 160 | mA |
| **VIDEO** | | | | | |
| Composite Video Input (Pin 34 or 36) | CVi | – | 1.0 | – | Vpp |
| Composite Video Output (Pin 49, Unterminated) | – | – | 2.0 | – | Vpp |
| Video Output DC Level (Sync Tip) | – | – | 1.0 | – | Vdc |
| Video Gain | – | – | 6.0 | – | dB |
| Video Frequency Response (Main Video to –1.0 dB) | – | – | 10 | – | MHz |
| Color Bar Accuracy | – | – | ±4.0 | – | deg |
| Video Crosstalk (@ 75% Color Bars)<br>Main to PIP<br>PIP to Main | – | <br>–<br>– | <br>55<br>55 | <br>–<br>– | dB |
| Output Impedance | – | – | 5.0 | – | Ω |
| **HORIZONTAL TIMEBASE** | | | | | |
| Free Run HPLL Frequency (Pin 16) | – | – | 15734 | – | Hz |
| HPLL Pull–In Range | – | – | ±400 | – | Hz |
| HPLL Jitter | – | – | ±4.0 | – | ns |
| Burst Gate Timing (from Trailing Edge Hsync, Pin 24) | – | – | 1.0 | – | µs |
| Burst Gate Width | – | – | 4.0 | – | µs |
| **VERTICAL TIMEBASE** | | | | | |
| Vertical Countdown Window | – | – | 232/296 | – | H lines |
| Vertical Sync Integration Time | – | – | 31 | – | µs |
| **ANALOG TO DIGITAL CONVERTER** | | | | | |
| Resolution | – | – | – | 6 | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| ADC – Y Frequency Response @ –5.0 dB | – | – | 1.0 | – | MHz |
| ADC – U, V Frequency Response @ –5.0 dB | – | – | 200 | – | kHz |
| Sample Clock Frequency (4/3 $F_{SC}$) | – | – | 4.773 | – | MHz |

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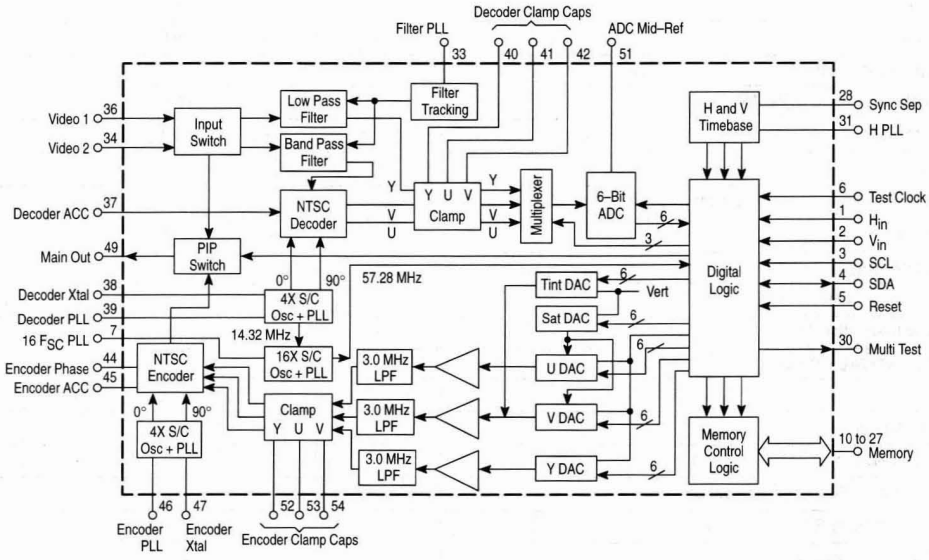
**ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = $V_{DD}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

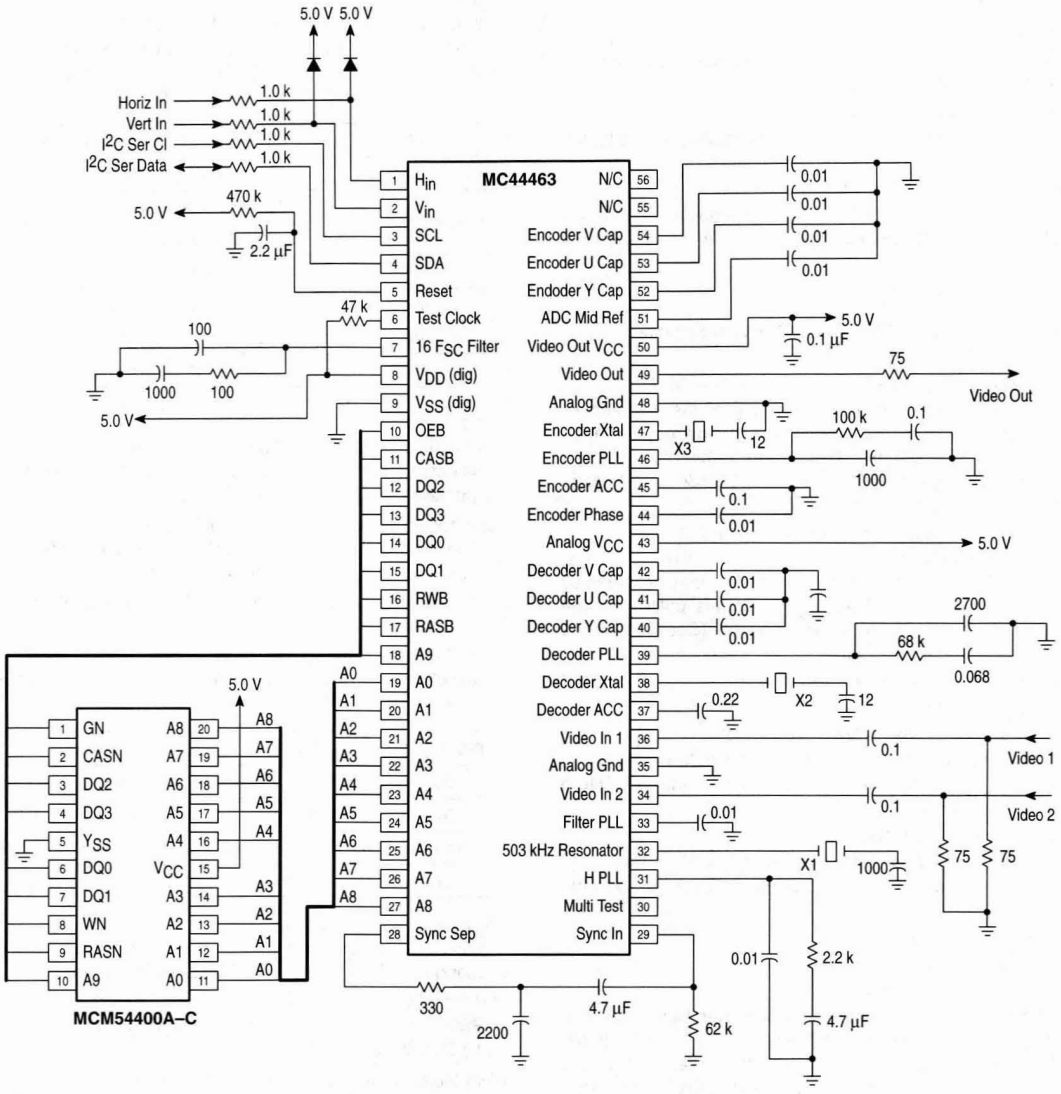
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DIGITAL TO ANALOG CONVERTER** | | | | | |
| Resolution | – | – | – | 6 | Bits |
| Integral Non–Linearity | – | – | ±1 | – | LSB |
| Differential Non–Linearity | – | – | +2/–1 | – | LSB |
| Tint DAC Control Range (in 64 Steps) | – | – | ±10 | – | Deg |
| Saturation DAC Control Range (in 64 steps) | – | – | ±6.0 | – | dB |
| **NTSC DECODER** | | | | | |
| Color Kill Threshold | – | – | –24/–16 | – | dB |
| Threshold Hysteresis | – | – | ±1.0 | – | dB |
| ACC (Chroma Amplitude Change, +3.0 dB to –12 dB) | – | – | ±5.0 | – | dB |
| **PIP CHARACTERISTICS** | | | | | |
| PIP Size | – | | | | |
| 1/9 Screen Horizontal | | – | 114 | – | pels |
| 1/9 Screen Vertical | | – | 71 | – | lines |
| 1/16 Screen Horizontal | | – | 84 | – | pels |
| 1/16 Screen Vertical | | – | 53 | – | lines |
| Border Size Horizontal | – | – | 3 | – | pels |
| Border Size Vertical | – | – | 2 | – | lines |
| Output PEL Clock (4 $F_{SC}$) | – | – | 14.318 | – | MHz |
| Position Control Range Horizontal (% of Main Picture), 64 Steps | – | – | 100 | – | % |
| Position Control Range Vertical (% of Main Picture), 64 Steps | – | – | 100 | – | % |

**Figure 1. Representative Block Diagram**




This device contains approximately 300,000 active transistors.

**Figure 2. Application Circuit**




X1 – 503 kHz – Murata Erie CSB503F2 or equivalent
X2 – 14.31818 MHz – Fox 143–20 or equivalent
X3 – 14.31818 MHz – Fox 143–20 or equivalent

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## I²C REGISTER DESCRIPTIONS

Base write address = 26h

Base read address = 27h

**Read Register**

There are two active bits in the single read byte available from the MC44463 as follows:

*Write Vertical Indicator (WVI0) – D7*

When 0 indicates that the write operation specified by the last I²C command has been completed.

*PIP Sync Detect Bit (PSD0) – D1*

When 0 indicates that the PIP video H pulses are present and the horizontal timebase oscillator is within acceptable limits.

**Write Registers**

**Read Start Position/Write Start Position Registers**
Sub–address = 00h

*Write Raster Position Start Bits (WPS0–2) – D0–D2*

Establishes the horizontal beginning of the PIP and its black level measurement gate. This beginning may be varied by approximately 3.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

*Read Raster Position Bits (RPS0–3) – D4–D7*

Establishes the clamp gate position for the black level reference for the main picture. This position may be varied by approximately 5.0 µs. The position of this pulse may be observed through the Multi Test Pin 30 (See Test Mode Register Sub–address 03h).

**Pip Switch Delay/Vertical Filter Register**
Sub–address = 01h

*PIP Switch Delay Bits (PSD0–3) – D0–D3*

Delays the start of PIP on time relative to the PIP picture. These bits are used to center the PIP border and PIP picture in the horizontal direction.

*Vertical Filter Bit (VFON) – D4*

When the filter is activated (VFON = 1) a three line weighted average is taken to provide the data stored in the field memory.

**Border Color Register**
Sub–address = 02h

*Border Color Bits (BC0–2) – D0–D2*

These Bits control the color of the border. Note that when using one of the saturated border colors it is possible to get objectionable dot crawl at the edge of the border in some TVs unless appropriate comb filtering is used in the TV circuitry.

| BC (2:0) | Border Color |
|---|---|
| 000 | Black |
| 001 | White 70% |
| 010 | No Border (clear) |
| 011 | No Border (clear) |
| 100 | Blue |
| 101 | Green |
| 110 | Red |
| 111 | White |

**Test Mode/Main Vertical and Horizontal Polarity Register**
Sub–address = 03h

*Internal Test Mode Register (ITM0–2) – D0–D2*

Sets the Multi Test Pin output to provide one of several internal signals for test and production alignment. Also controls the test memory address counter.

| ITM (2:0) | Multi–Test I/O and Function |
|---|---|
| 000 | Input – Analog Test mode |
| 001 | Input – Digital Test mode |
| 010 | Output – Sync Detect |
| 011 | Output – PIP Switch |
| 100 | Output – PIP H Detect |
| 101 | Output – PIP V Detect |
| 110 | Output – PIP Clamp |
| 111 | Output – Main Clamp |

*Main vertical polarity select bit (MVP0) – D6*

Selects polarity of active level of vertical reference input. 0 = positive going, 1 = negative going.

*Main horizontal polarity select bit (MHP0) – D7*

Selects polarity of active level of horizontal reference input. 0 = positive going, 1 = negative going.

**PIP Freeze/PIP Size/Main and PIP Video Source Register**
Sub–address = 04h

*LIVE PIP Select Bits (LIVE_P0–1) – D0–D1*

Selects which of the mutliple PIP pictures is the active "live" one.

| LIVE_P (1:0) | 1/16 Size | 1/9 Size |
|---|---|---|
| 00 | Top = LIVE | Top = LIVE |
| 01 | 2nd from Top = LIVE | 2nd from Top = LIVE |
| 10 | 3rd from Top = LIVE | 3rd from Top = LIVE |
| 11 | 4th from Top = LIVE | 3rd from Top = LIVE |

*PIP Freeze Bit (STIL0) – D4*

When set to one, the most recently received field is continuously displayed until the freeze bit is cleared.

*PIP Size Bit (PSI90) – D5*

Switches the PIP size between 1/16 main size (when 0) and 1/9 main size (when 1).

*Main Video Source Select Bit (MSEL0) – D6*

Selects which video input will be applied to the PIP switch as the main video out.

*PIP Video Source Select Bit (PSEL0) – D7*

Selects which video input will be applied to the video decoder to provide the PIP video.

| MSEL/PSEL | Function |
|---|---|
| 0 | Video 1 Input to Main/<br>Video 1 Input to PIP |
| 1 | Video 2 Input to Main/<br>Video 2 Input to PIP |

**PIP On/PIP Blank Register**
Sub–address = 05h

*PIP On Bits (PON0–3) – D4–D3*
When on (1) turns the corresponding PIP display on.

| PON (3:0) | 1/16 Size | 1/9 Size |
|---|---|---|
| 0000 | No PIP | No PIP |
| 0001 | Top = On | Top = On |
| 0010 | 2nd from Top = On | 2nd from Top = On |
| 0100 | 3rd from Top = On | 3rd from Top = On |
| 1000 | 4th from Top = On | 3rd from Top = On |

*PIP Blanking Bits (PBL0–3) – D4–D7*
When on (1) sets the corresponding PIP to black. If the individual PIP is off, then it will be black when it is turned on.

| PBL (7:4) | Function |
|---|---|
| 0000 | PIP Picture Normal |
| 0001 | Top = Blanked (Set to Black) |
| 0010 | 2nd from Top = Blanked (Set to Black) |
| 0100 | 3rd from Top = Blanked (Set to Black) |
| 1000 | 4th from Top = Blanked (Set to Black) |

**PIP X Position Register**
Sub–address = 06h

*X Position Bits (XPS0–5) – D0–D5*
Moves the PIP start position from the left to the right edge of the display in 64 steps. There is protection circuitry to prevent the PIP from interfering with the main picture sync pulses.

**PIP Y Position Register**
Sub–address = 07h

*Y Position Bits (YPS0–5) – D0–D5*
Moves the PIP start position from the top to the bottom edge of the display in 64 steps. There is protection circuitry to prevent the PIP from interfering with the main picture sync pulses.

**PIP Chroma Level Register**
Sub–address = 08h

*Chroma (C0–5) – D0–D5*
The color of the PIP can be adjusted to suit viewer preference by setting the value stored in these bits. A total of 64 steps varies the color from no color to maximum. This control acts in conjunction with the auto phase control.

**PIP Tint Level Register**
Sub–address = 09h

*Tint (T0–5) – D0–D5*
An auto phase control compares the main color burst to the internally generated pseudo color burst so that the tints are matched. In addition to this, the tint of the PIP can be varied ±10° in a total of 64 steps by changing the value of these bits to suit viewer preference.

**PIP Luma Delay Register**
Sub–address = 0Ah

*Y Delay (YDL0–2) – D0–D2*
Since the Chroma passes through a bandpass filter and the color decoder, it is delayed with respect to the Luma signal. Therefore, to time match the Luma and Chroma these bits are set to a single value determined to be correct in the application.

**PIP Acquire/Playback Register**
Sub–address = 0Bh

*PIP Acquire Speed Bits (ACQ_SP0–1) – D0–D1*
These select the speed of the video acquisition. This is only active when RE_AQ = 1.

| ACQ_SP (1:0) | Function |
|---|---|
| 00 | Acquire 1 Out of Every 4 Fields |
| 01 | Acquire 1 Out of Every 6 Fields |
| 10 | Acquire 1 Out of Every 8 Fields |
| 11 | Acquire 1 Out of Every 10 Fields |

*PIP Save/Clear Bit (RE_AQ) –D2*
This bit controls the save and clear function for the instant replay. The bit value 1 is only effective when PON0–3 = 0000. (No PIP display.)

| RE_AQ (2:2) | Function |
|---|---|
| 0 | Save Memory |
| 1 | Clear Reacquire |

*PIP Playback Speed Bits (PB_SP0–1) – D4–D5*
These bits control the relative playback speed, to the acquired speed.

| PB_SP (5:4) | Function |
|---|---|
| 00 | Playback at 1 x ACQ_SP Speed |
| 01 | Playback at 1/2 x ACQ_SP Speed |
| 10 | Playback at 1/4 x ACQ_SP Speed |
| 11 | Playback at 1/8 x ACQ_SP Speed |

*PIP Playback Control Bit (PB) – D6*
This bit controls the start/stop of the instant replay function.

| PB (6:6) | Function |
|---|---|
| 0 | No Action |
| 1 | Instant Replay Activated |

**PIP Fill/Background/Free Run/Test Register**
Sub–address = 0Ch

*PIP Fill Bits (PIPFILL0–1) – D0–D1*
May be used to fill the PIP with one of three selectable solid colors

| PIPFILL (1:0) | Function |
|---|---|
| 00 | Normal |
| 01 | Red |
| 10 | Green |
| 11 | Blue |

*Test Register Bits (INTC0 and MACR0) – D6–D7*
When the FRUN is set to 1 the circuitry provides a generated sync and displays a flat field that can be either dark blue or gray determined by the BGND bit.

| BGND (2:2) | Function |
|---|---|
| 0 | Blue |
| 1 | 50% White |

9

## I²C REGISTER TABLE

| Sub–address | Data Bit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| 00 | RPS3 | RPS2 | RPS1 | RPS0 | – | WPS2 | WPS1 | WPS0 |
| 01 | – | – | – | VFON | PSD3 | PSD2 | PSD1 | PSD0 |
| 02 | – | – | – | – | – | BC2 | BC1 | BC0 |
| 03 | MHP0 | MVP0 | – | – | – | ITM2 | ITM1 | ITM0 |
| 04 | PSEL0 | MSEL0 | PSI90 | STIL0 | – | – | LIVE_P1 | LIVE_P0 |
| 05 | PBL3 | PBL2 | PBL1 | PBL0 | PON3 | PON2 | PON1 | PON0 |
| 06 | – | – | XPS5 | XPS4 | XPS3 | XPS2 | XPS1 | XPS0 |
| 07 | – | – | YPS5 | YPS4 | YPS3 | YPS2 | YPS1 | YPS0 |
| 08 | – | – | C5 | C4 | C3 | C2 | C1 | C0 |
| 09 | – | – | T5 | T4 | T3 | T2 | T1 | T0 |
| 0A | – | – | – | – | – | YDL2 | YDL1 | YDL0 |
| 0B | – | PB | PB_SP1 | PB_SP0 | – | RE_AQ | ACQ_SP1 | ACQ_SP0 |
| 0C | INTC | MACR | FRUN | – | – | BGND | PIPFILL1 | PIPFILL0 |

**Function Control of the MC44463**

There are three modes of operation; Single PIP, Multiple PIP and Replay. These are enabled by setting specific register bits in the I²C register set.

*Single PIP (SPIP) Operation*

Register 0Bh : D6 –> 0

Register 05h : D0–D7 –> 01h

*Multiple PIP (MPIP) Operation*

Register 05h : D0–D3 –> 07h or 0Fh

Register 04h : D0–D1 –> 0 to 3

Register 0Bh : D6 –> 0

Register 0Ch : D5 –> 1, D2 –> 0 or 1 (Optional)

*Replay PIP (RPIP) Operation*

In sequence, the Capture Ready mode must be first activated, allowing up to 8 seconds of fill memory with the desired video stream. Then the Capture mode must be set, disabling further write to memory. The Capture data may be re–displayed at any time afterword.

*Capture Ready*

Register 05h : D0–D3 –> 0

Register 0Bh : D6 –> 0, D2 –> 1, D0–D1 –> 0 to 3

*Capture*

Register 0Bh : D6 –> 1, D2 –> 0, D4–D5 –> 0 to 3

Register 05h: D0 –> 1

MOTOROLA

# MC44817/17B

## PLL Tuning Circuits with 3-Wire Bus

**TV AND VCR PLL TUNING CIRCUITS WITH 1.3 GHz PRESCALER AND 3–WIRE BUS**

**SEMICONDUCTOR TECHNICAL DATA**

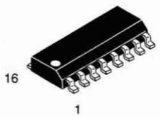
The MC44817/17B are tuning circuits for TV and VCR tuner applications. They contain on one chip all the functions required for PLL control of a VCO. The integrated circuits also contain a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44817 has programmable 512/1024 reference divider while the MC44817B has a fixed reference divider of 1024.

The MC44817/17B are manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

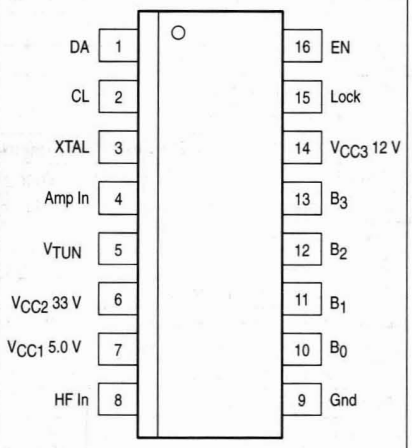
- Complete Single Chip System for MPU Control (3–Wire Bus). Data and Clock Inputs are IIC Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider Accepts Input Frequencies up to 165 MHz
- Reference Divider: Programmable for Division Ratios 512 and 1024. The MC44817B has a Fixed 1024 Reference Divider
- Tri–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Integrated PNP Band Buffers for 40 mA ($V_{CC1}$ to 14.4 V)
- Output Options for the Reference Frequency and the Programmable Divider
- Bus Protocol for 18 or 19 Bit Transmission
- Extra Protocol for 34 Bit for Test and Further Features
- High Sensitivity Preamplifier
- Circuit to Detect Phase Lock
- Fully ESD Protected

MOSAIC is a trademark of Motorola, Inc.




**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

**PIN CONNECTIONS**

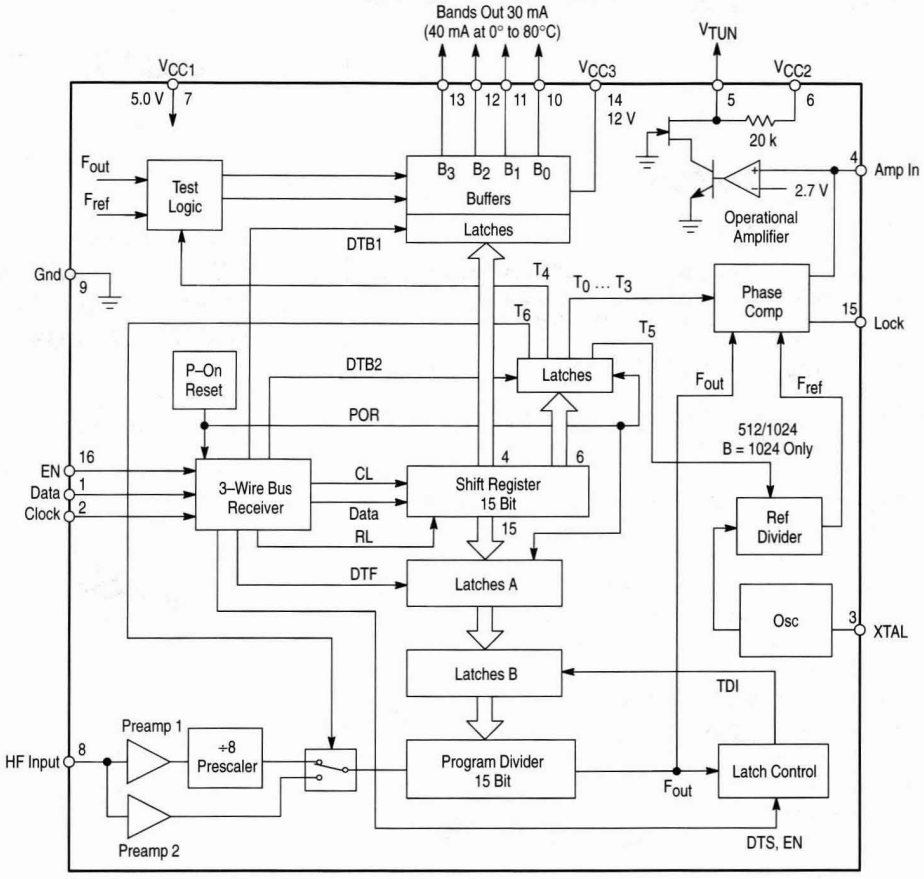



(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44817D | $T_A = -20°$ to $+80°C$ | SO–16 |
| MC44817BD | | |

**Representative Block Diagram**




This device contains 3,204 active transistors.

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage ($V_{CC1}$) | 7 | 6.0 | V |
| Band Buffer "Off" Voltage | 10–13 | 14.4 | V |
| Band Buffer "On" Current | 10–13 | 50 | mA |
| Band Buffer – Short Circuit Duration (0 to $V_{CC3}$) (Note 2) | 10–13 | Continuous | – |
| Operational Amplifier Power Supply Voltage ($V_{CC2}$) | 6 | 40 | V |
| Operational Amplifier Short Circuit Duration (0 to $V_{CC2}$) | 5 | Continuous | – |
| Power Supply Voltage ($V_{CC3}$) | 14 | 14.4 | V |
| Storage Temperature | – | –65 to +150 | °C |
| Operating Temperature Range | – | –20 to +80 | °C |
| Band Buffer Operation (Note 1) at 50 mA each Buffer<br>All Buffers "On" Simultaneously | 10–13 | 10 | sec |
| Operational Amplifier Output Voltage | 5 | $V_{CC2}$ | V |
| RF Input Level (10 MHz to 1.3 GHz) | – | 1.5 | Vrms |

**NOTES:** 1. At $V_{CC3} = V_{CC1}$ to 14.4 V and $T_A = -20°$ to +80°C.
2. At $V_{CC3} = V_{CC1}$ to 14.4 V and $T_A = -20°$ to +80°C one buffer "On" only.

**ELECTRICAL CHARACTERISTICS** ($V_{CC1}$ = 5.0 V, $V_{CC2}$ = 33 V, $V_{CC3}$ = 12 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $V_{CC1}$ Supply Voltage Range | 7 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC1}$ Supply Current ($V_{CC1}$ = 5.0 V) | 7 | – | 37 | 50 | mA |
| $V_{CC2}$ Supply Voltage Range | 6 | 25 | – | 37 | V |
| $V_{CC2}$ Supply Current (Output Open) | 6 | – | 1.5 | 3.5 | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 10–13 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 30 mA | 10–13 | – | 0.15 | 0.3 | V |
| Band Buffer Saturation Voltage when "On" at 40 mA only for 0° to 80°C | 10–13 | – | 0.2 | 0.5 | V |
| Data/Clock/Enable Current at 0 V | 1, 2, 16 | –10 | – | 0 | µA |
| Data/Clock/Enable Current at 5.0 V | 1, 2, 16 | 0 | – | 1.0 | µA |
| Data/Clock/Enable Input Voltage Low | 1, 2, 16 | – | – | 1.5 | V |
| Data/Clock/Enable Input Voltage High | 1, 2, 16 | 3.0 | – | – | V |
| Clock Frequency Range | 2 | – | – | 100 | kHz |
| Oscillator Frequency Range | 3 | 3.15 | 3.2 | 4.05 | MHz |
| Operational Amplifier Internal Reference Voltage | – | 2.0 | 2.75 | 3.2 | V |
| Operational Amplifier Input Current | 4 | –15 | 0 | 15 | nA |
| DC Open Loop Voltage Gain | – | 100 | 250 | – | V/V |
| Gain Bandwidth Product (CL = 1.0 nF) | – | 0.3 | – | – | MHz |
| $V_{out}$ Low, Sinking 50 µA | 5 | – | 0.2 | 0.4 | V |
| $V_{out}$ High, Sourcing 10 µA, $V_{CC2} - V_{out}$ | 5 | – | 0.2 | 0.5 | V |
| Phase Comparator Tri–State Current | 4 | –15 | 0 | 15 | nA |
| Charge Pump High Current of Phase Comparator | 4 | 30 | 50 | 85 | µA |
| Charge Pump Low Current of Phase Comparator | 4 | 10 | 15 | 30 | µA |
| $V_{CC3}$ Supply Voltage Range | 14 | $V_{CC1}$ | – | 14.4 | V |
| $V_{CC3}$ Supply Current | 14 | | | | mA |
| All Buffers "Off" | | – | 0.2 | 0.5 | |
| One Buffer "On" when Open | | – | 8.0 | 13 | |
| One Buffer "On" at 40 mA | | – | 48 | 53 | |

**Data Format and Bus Receiver**

The circuit is controlled by a 3–wire bus via Data (DA), Clock (CL), and Enable (EN) inputs. The Data and Clock inputs may be shared with other inputs on the IIC–Bus while the Enable is a separate signal. The circuit is compatible with 18 and 19 bit data transmission and also has a mode for 34 bit transmission for test and additional features.

The 3–wire bus receiver receives data for the internal shift register after the positive going edge of the EN–signal. The data is transmitted to the band buffers on the negative going edge of the clock pulse 4 (signal DTB1).

**18 and 19 Bit Data Transmission**

The programmable divider may receive 14 bit (18 bit transmission) or 15 bit (19 bit transmission). The data is transmitted to the programmable divider (latches A) on the negative going edge of clock pulse 19 or on the negative edge of the EN–signal if EN goes down after the 18th clock pulse (signal DTF). If the programmable divider receives 14 bit, its MSB (bit $N_{14}$) is internally reset. The reset pulse is generated only if EN goes negative after the 18th clock pulse (signal RL).

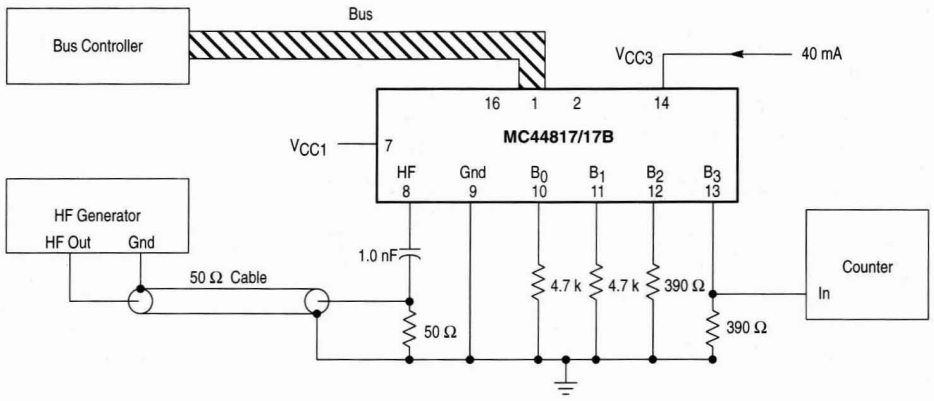
**34 Bit Data Transmission (For Test and Additional Features)**

In the test mode, the programmable divider receives 15 bit and the data is transferred to latches A on the negative edge of clock pulse 19 (signal DTF). The information for test is received on clock pulses 20 to 26 and transmitted to the latches on the negative edge of pulse 34 (signal DTB2). These latches have a power–on reset. The power–on reset sets the programmable divider to a counting ratio of 256 or higher and resets the corresponding latches to the test bits $T_0$ to $T_6$ (signal POR). The bus receiver is not disturbed if the data format is wrong. Useless bits are ignored. If for example the Enable signal goes low after the clock pulse 9, bits one to four are accepted as valid buffer information and the other bits are ignored. If more than 34 bits are received, bit 35 and the following are ignored.

**Lock Detector**

The lock–detector output is low in lock. The output goes immediately high when an unlock condition is detected. The output goes low again when the loop is in lock during a complete period of the reference frequency.

**Figure 1. HF Sensitivity Test Circuit**




Device is in test mode. $B_2$, $B_3$ are "On" and $B_0$, $B_1$ are "Off".
Sensitivity is level of HF generator on 50 Ω load (without Pin 8 loading).

**HF CHARACTERISTICS** (See Figure 1)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| DC Bias | 8 | – | 1.6 | – | V |
| Input Voltage Range | | | | | mVrms |
| 10–80 MHz, Prescaler "Off", $T_6$ = 1.0 | 8 | 20 | – | 315 | |
| 80–150 MHz | 8 | 10 | – | 315 | |
| 150–600 MHz | 8 | 5.0 | – | 315 | |
| 600–950 MHz | 8 | 10 | – | 315 | |
| 950–1300 MHz | 8 | 50 | – | 315 | |

**Figure 2. Typical HF Input Impedance**

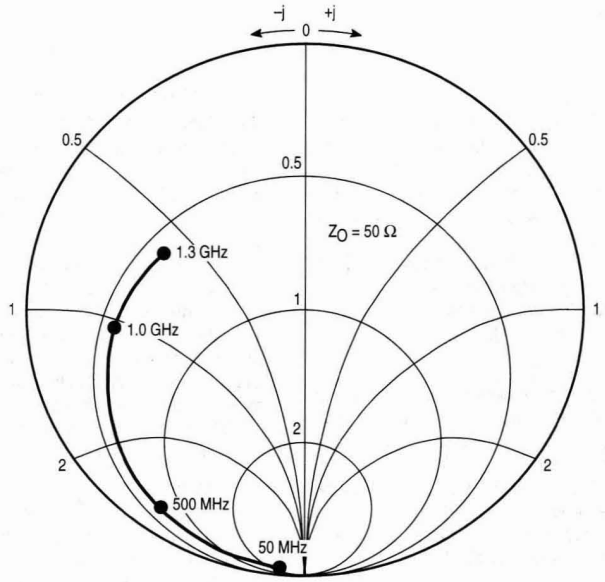
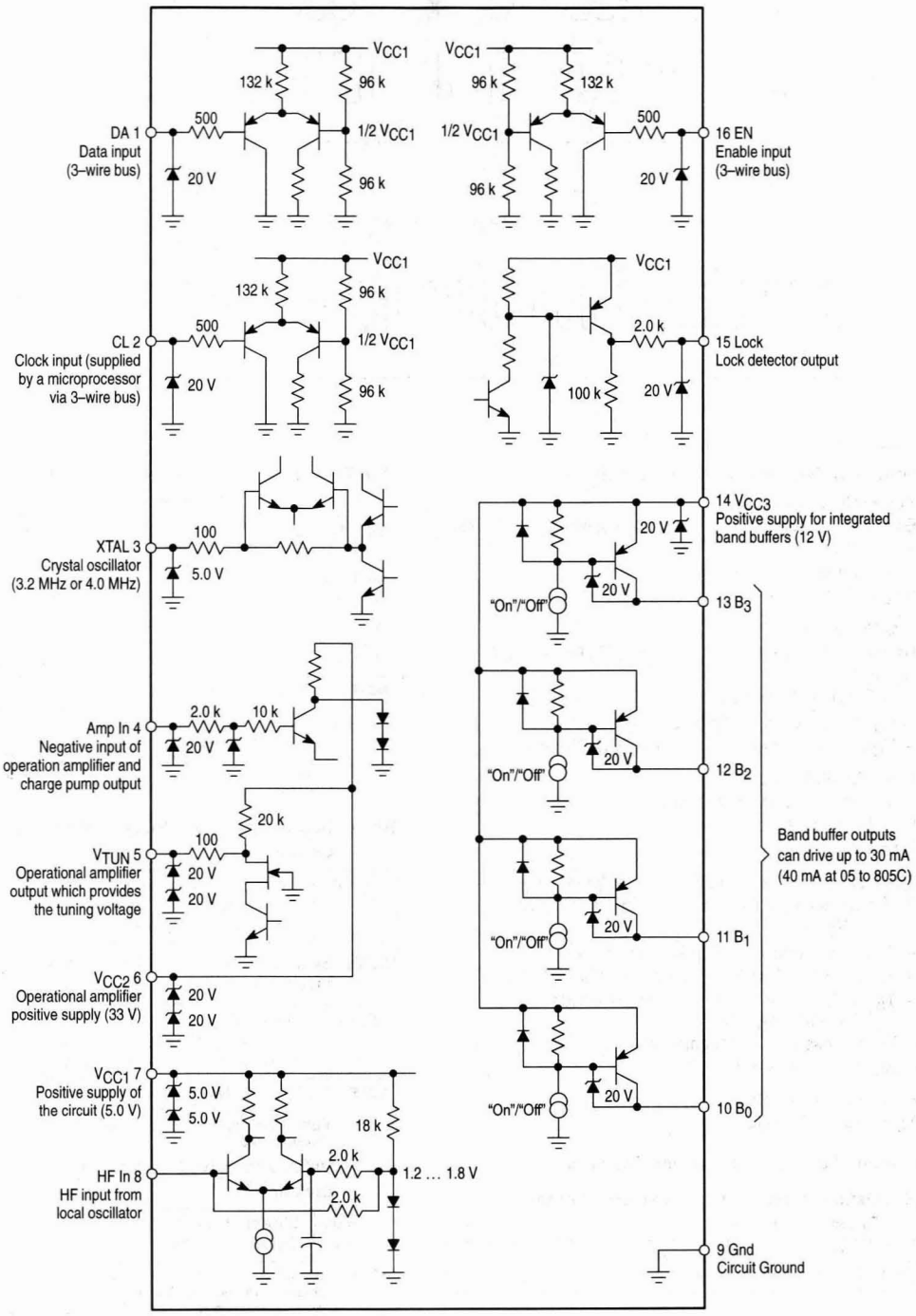
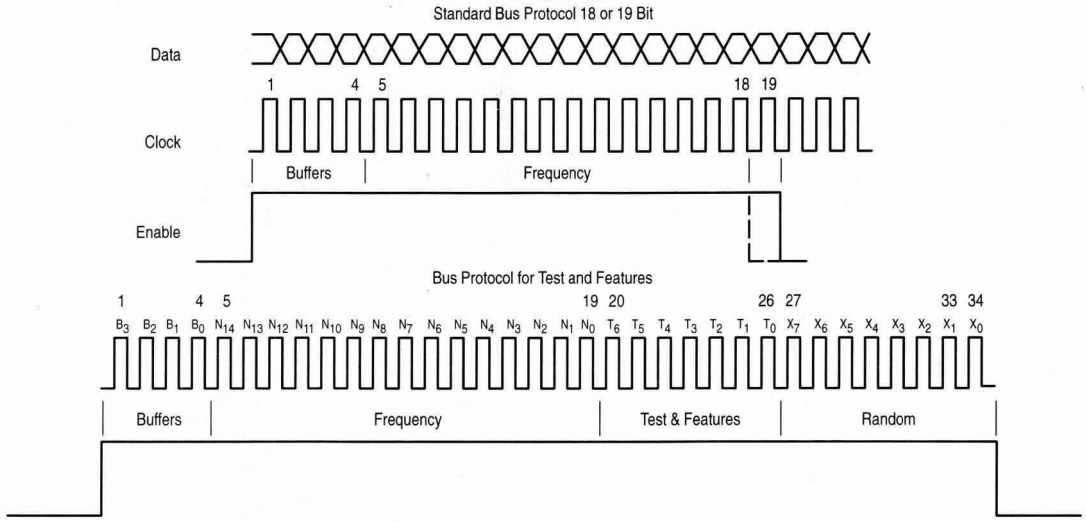


**Figure 3. Pin Circuit Schematic**



### Bus Timing Diagram




**Definition of Permissible Bus Protocols**

1. Bus Protocol for 18 Bit
   $B_3$ $B_2$ $B_1$ $B_0$ $N_{13}$ $N_{12}$ $N_{11}$ $N_{10}$ $N_9$ $N_8$ $N_7$ $N_6$ $N_5$ $N_4$ $N_3$ $N_2$ $N_1$ $N_0$
   Max Counting Ratio 16363
   $N_{14}$ is Reset Internally

2. Bus Protocol for 19 Bit
   $B_3$ $B_2$ $B_1$ $B_0$ $N_{14}$ $N_{13}$ $N_{12}$ $N_{11}$ $N_{10}$ $N_9$ $N_8$ $N_7$ $N_6$ $N_5$ $N_4$ $N_3$ $N_2$ $N_1$ $N_0$
   Max Counting Ratio 32767
   - $B_0$ to $B_3$: Control of Band Buffers
   - $N_0$ to $N_{14}$: Control of Programmable Dividers

   $N_{14}$ = MSB; $N_0$ = LSB
   Minimum Counting Ratio Always 17
   $B_3$ = First Shifted Bit
   $N_0$ = Last Shifted Bit

3. Bus Protocol for Test and Further Features (34 Bit)
   $B_3$ $B_2$ $B_1$ $B_0$ $N_{14}$...$N_0$ $T_6$ $T_5$ $T_4$ $T_3$ $T_2$ $T_1$ $T_0$ $X_7$ $X_6$...$X_1$ $X_0$
   - $T_0$ to $T_3$: Control the Phase Comparator
   - $T_4$: Switches Test Signals to the Buffer Outputs
   - $T_5$: Division Ratio of the Reference Divider
     B Version $T_5$ = "X"
   - $T_6$: Bypasses the Prescaler (Note 1)
   - $X_0$ to $X_7$: Are Random

   $B_3$ = First Shifted Bit
   $X_0$ = Last Shifted Bit

**Definition of the Bits for Test and Features**

**Bit $T_0$: Defines the Charge Pump Current of the Phase Comparator**

| | |
|---|---|
| $T_0$ = 0 | Pump Current 50 µA Typical |
| = 1 | Pump Current 15 µA Typical |

**Bits $T_1$ and $T_2$: Define the Digital Function of the Phase Comparator**

| $T_2$ | $T_1$ | State | Output Function of Phase Comparator |
|---|---|---|---|
| 0 | 0 | 1 | Normal Operation |
| 0 | 1 | 2 | High Impedance (Tri–State) |
| 1 | 0 | 3 | Upper Source "On", Lower Source "Off" |
| 1 | 1 | 4 | Lower Source "On", Upper Source "Off" |

**NOTE:** 1. The phase comparator pulls high if the input frequency is too high and it pulls low when the input frequency is too low. (Inversion by Operational Amplifier) The phase comparator generates a fixed duration offset pulse for each comparison pulse (similar to the MC44802A). This guarantees operation in the linear region. The offset pulse is a positive current pulse (upper source).

**Bit $T_3$: Defines the Offset Pulse of the Phase Comparator**

| | |
|---|---|
| $T_3$ = 0 | Offset Pulse Short (200 ns)<br>Normal Mode |
| = 1 | Offset Pulse Long (350 ns) |

**Bit $T_4$: Switches the Internal Frequencies $F_{ref}$ and FBY2 to the Buffer Outputs ($B_2$, $B_3$)**

| | |
|---|---|
| $T_4$ = 0 | Normal Operation |
| = 1 | $F_{ref}$ Switched to Buffer Output $B_2$<br>FBY2 Switched to Buffer Output $B_3$ |

**NOTE:** Bits $B_2$ and $B_3$ have to be one in this case.
$F_{ref}$ is the reference frequency.
FBY2 is the output frequency of the programmable divider, divided by two.

**Bit $T_5$: Defines the Division Ratio of the Reference Divider**

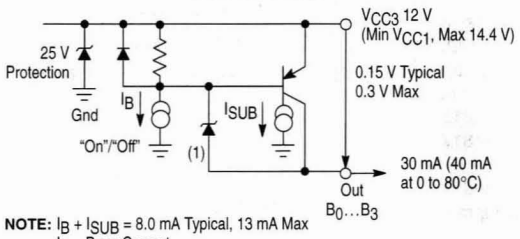
| | |
|---|---|
| $T_5$ = 0 | Division Ratio 512 |
| = 1 | Division Ratio 1024 |

**NOTE:** The division ratio of the reference divider can only be programmed in the 34 bit bus protocol.
In the standard bus protocol the division ratio is 512.
(The power–up reset POR sets the division ratio to 512).
On "B–version", $T_5$ = "X". Division ratio 1024 fixed.

**Bit $T_6$: Switches the Prescaler**

| | |
|---|---|
| $T_6$ = 0 | Normal Operation, 1.3 GHz |
| = 1 | Low Frequency Operation<br>Preamp. 2 Switched Off, 165 MHz maximum<br>The prescaler is bypassed and the power supply of the prescaler is switched off. Input: 10 MHz minimum, 20 mVrms minimum |

**Figure 4. Equivalent Circuit of the Integrated Band Buffers**




**NOTE:** $I_B + I_{SUB}$ = 8.0 mA Typical, 13 mA Max
$I_B$ = Base Current
$I_{SUB}$ = Substrate Current of PNP

**The Programmable Divider**

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider; this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8132 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

(16363 in case of 18 bit bus protocol)

Minimum Ratio 17

$N_0$ ... $N_{14}$ are the different bits for frequency information.

At power–on the whole bus receiver is reset and the programmable divider is set to a counting ratio of N = 256 or higher.

**The Prescaler**

The prescaler has a preamplifier which guarantees high input sensitivity.

**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**The Operational Amplifier**

The operational amplifier is designed for very low noise, low input bias current and high power supply rejection. The positive input is biased internally. The operational amplifier needs 28.5 V supply ($V_{CC2}$) as minimum voltage for a guaranteed maximum tuning voltage of 28 V.

Figure 6 shows a possible filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

**The Oscillator**

The oscillator uses a 3.2 to 4.0 MHz crystal tied to ground in series with a capacitor. The crystal operates in the series resonance mode.

The voltage at Pin 3 has low amplitude and low harmonic distortion.

**Figure 5. Equivalent Circuit of the Lock Output**

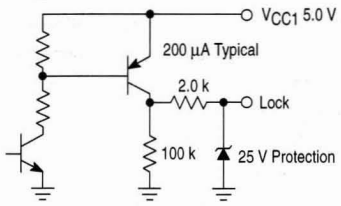
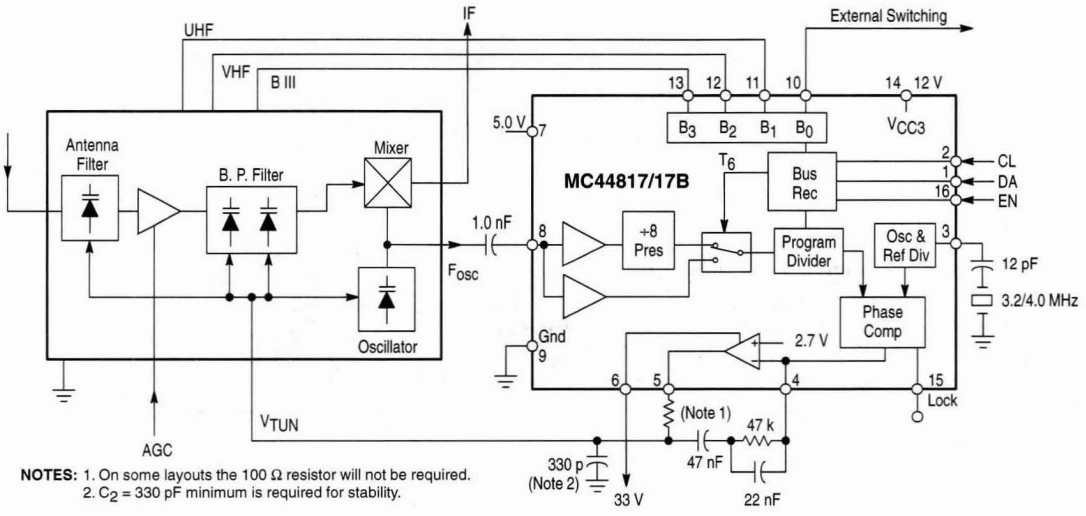



**Figure 6. Typical Tuner Application**




**NOTES:** 1. On some layouts the 100 Ω resistor will not be required.
2. $C_2$ = 330 pF minimum is required for stability.

MOTOROLA

# MC44818

## PLL Tuning Circuit with I2C Bus

**TV AND VCR PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND I2C BUS**

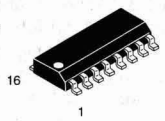
**SEMICONDUCTOR TECHNICAL DATA**

The MC44818 is a tuning circuit for TV and VCR tuner applications. It contains, on one chip, all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz. The MC44818 is a pin compatible drop in replacement for the MC44817, where the only difference is the MC44818 has a fixed divide–by–8 prescaler (cannot be bypassed) and the MC44817 uses the three wire bus.

The MC44818 has a programmable 512/1024 reference divider and is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

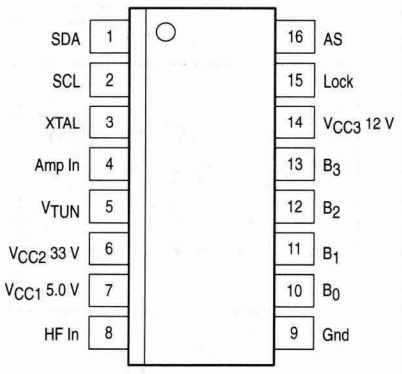
- Complete Single Chip System for MPU Control (I2C Bus). Data and Clock Inputs are 3–Wire Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider Accepts Input Frequencies up to 165 MHz
- Reference Divider: Programmable for Division Ratios 512 and 1024.
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Integrated PNP Band Buffers for 40 mA ($V_{CC1}$ to 14.4 V)
- Output Options for the Reference Frequency and the Programmable Divider
- High Sensitivity Preamplifier
- Circuit to Detect Phase Lock
- Fully ESD Protected

MOSAIC is a trademark of Motorola, Inc.




**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

**PIN CONNECTIONS**



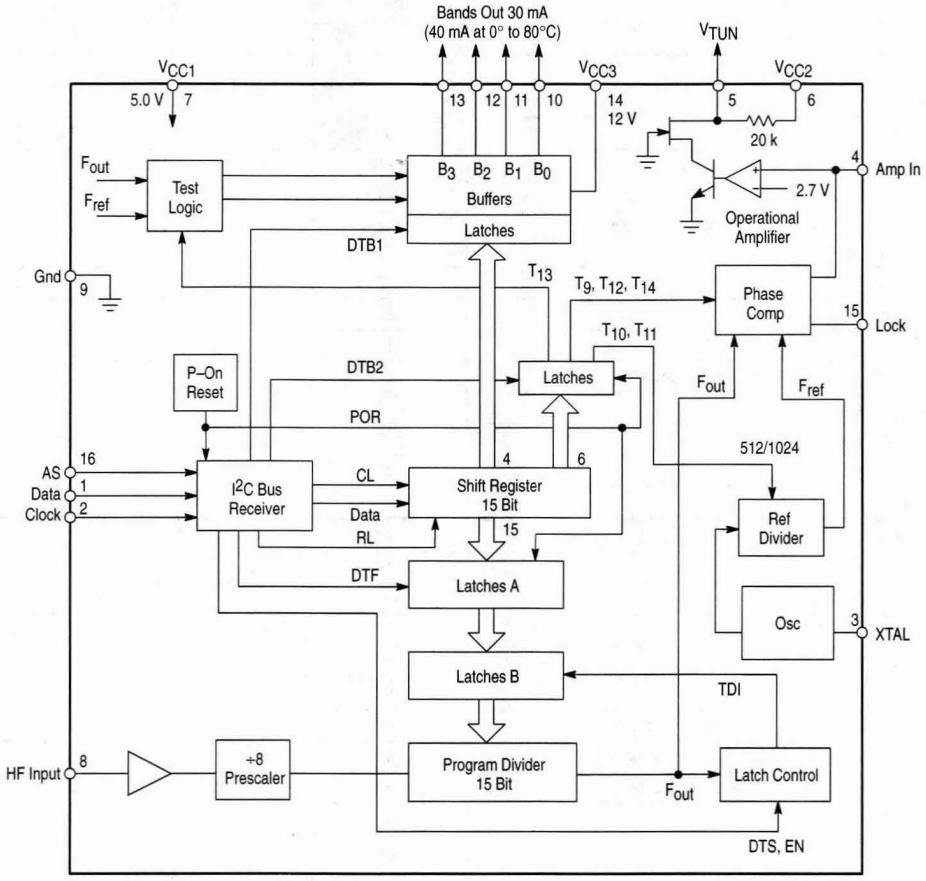

(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44818D | $T_A$ = –20° to +80°C | SO–16 |

9

**Representative Block Diagram**




This device contains 3,204 active transistors.

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage ($V_{CC1}$) | 7 | 6.0 | V |
| Band Buffer "Off" Voltage | 10–13 | 14.4 | V |
| Band Buffer "On" Current | 10–13 | 50 | mA |
| Band Buffer – Short Circuit Duration (0 to $V_{CC3}$) (Note 2) | 10–13 | Continuous | – |
| Operational Amplifier Power Supply Voltage ($V_{CC2}$) | 6 | 40 | V |
| Operational Amplifier Short Circuit Duration (0 to $V_{CC2}$) | 5 | Continuous | – |
| Power Supply Voltage ($V_{CC3}$) | 14 | 14.4 | V |
| Storage Temperature | – | –65 to +150 | °C |
| Operating Temperature Range | – | –20 to +80 | °C |
| Band Buffer Operation (Note 1) at 50 mA each Buffer All Buffers "On" Simultaneously | 10–13 | 10 | sec |
| Operational Amplifier Output Voltage | 5 | $V_{CC2}$ | V |
| RF Input Level (10 MHz to 1.3 GHz) | – | 1.5 | Vrms |

**NOTES:** 1. At $V_{CC3}$ = $V_{CC1}$ to 14.4 V and $T_A$ = –20° to +80°C.
2. At $V_{CC3}$ = $V_{CC1}$ to 14.4 V and $T_A$ = –20° to +80°C one buffer "On" only.

**ELECTRICAL CHARACTERISTICS** ($V_{CC1}$ = 5.0 V, $V_{CC2}$ = 33 V, $V_{CC3}$ = 12 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $V_{CC1}$ Supply Voltage Range | 7 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC1}$ Supply Current ($V_{CC1}$ = 5.0 V) | 7 | – | 37 | 50 | mA |
| $V_{CC2}$ Supply Voltage Range | 6 | 25 | – | 37 | V |
| $V_{CC2}$ Supply Current (Output Open) | 6 | – | 1.5 | 2.3 | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 10–13 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 30 mA | 10–13 | – | 0.15 | 0.3 | V |
| Band Buffer Saturation Voltage when "On" at 40 mA only for 0° to 80°C | 10–13 | – | 0.2 | 0.5 | V |
| Data/Clock Current at 0 V | 1, 2 | –10 | – | 0 | µA |
| Clock Current at 5.0 V | 2 | 0 | – | 1.0 | µA |
| Data Current at 5.0 V Acknowledge "Off" | 1 | 0 | – | 1.0 | µA |
| Data Saturation Voltage at 15 mA Acknowledge "On" | 1 | – | – | 1.0 | V |
| Data/Clock Input Voltage Low | 1, 2 | – | – | 1.5 | V |
| Data/Clock Input Voltage High | 1, 2 | 3.0 | – | – | V |
| Clock Frequency Range | 2 | – | – | 100 | kHz |
| Oscillator Frequency Range | 3 | 3.15 | 3.2 | 4.05 | MHz |
| Operational Amplifier Internal Reference Voltage | – | 2.0 | 2.75 | 3.2 | V |
| Operational Amplifier Input Current | 4 | –15 | 0 | 15 | nA |
| DC Open Loop Voltage Gain | – | 100 | 250 | – | V/V |
| Gain Bandwidth Product ($C_L$ = 1.0 nF) | – | 0.3 | – | – | MHz |
| $V_{out}$ Low, Sinking 50 µA | 5 | – | 0.2 | 0.4 | V |
| $V_{out}$ High, Sourcing 10 µA, $V_{CC2} - V_{out}$ | 5 | – | 0.2 | 0.5 | V |
| Phase Detector Current in the High Impedance State | 4 | –15 | 0 | 15 | nA |
| Charge Pump High Current of Phase Comparator | 4 | 30 | 50 | 85 | µA |
| Charge Pump Low Current of Phase Comparator | 4 | 10 | 15 | 30 | µA |
| $V_{CC3}$ Supply Voltage Range | 14 | $V_{CC1}$ | – | 14.4 | V |
| $V_{CC3}$ Supply Current | 14 | | | | mA |
| All Buffers "Off" | | – | 0.2 | 0.5 | |
| One Buffer "On" when Open | | – | 8.0 | 13 | |
| One Buffer "On" at 40 mA | | – | 48 | 53 | |

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**Data Format and Bus Receiver**

The circuit receives the information for tuning and control via the $I^2C$ bus. The incoming information, consisting of a chip address byte followed by two or four data bytes, is treated in the $I^2C$ bus receiver. The definition of the permissible bus protocol is shown below:

1_STA CA CO BA STO
2_STA CA FM FL STO
3_STA CA CO BA FM FL STO
4_STA CA FM FL CO BA STO

STA = Start Condition
STO = Stop Condition
CA = Chip Address Byte
CO = Data Byte for Control Information
BA = Band Information
FM = Data Byte for Frequency Information
FL = Data Byte for Frequency Information

**Figure 1. Complete Data Transfer Process**

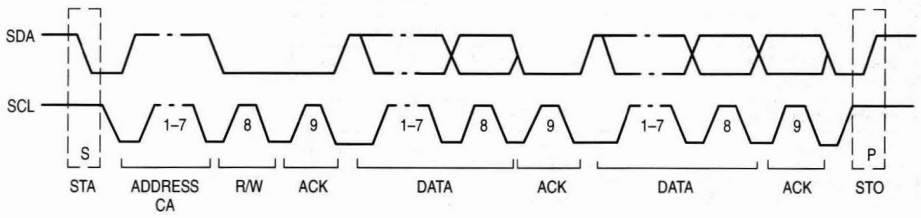


Figure 2 shows the five bytes of information that are needed for circuit operation: there is the chip address, two bytes of control and band information and two bytes of frequency information.

After the chip address, two or four data bytes may be received: if three data bytes are received the third data byte is ignored.

If five or more data bytes are received the fifth and following data bytes are ignored and the last acknowledge pulse is sent at the end of the fourth data byte.

The first and the third data bytes contain a function bit which allows the IC to distinguish between frequency information and control plus band information.

Frequency information is preceeded by a Logic "0". If the function bit is Logic "1" the two following bytes contain control and band information. The first data byte, shifted after the chip address, may be byte CO or byte FM.

The two permissible bus protocols with five bytes are shown in Figure 2.

**Figure 2. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | X | X | X | X | $B_3$ | $B_2$ | $B_1$ | $B_0$ | ACK |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | X | X | X | X | $B_3$ | $B_2$ | $B_1$ | $B_0$ | ACK |

### Chip Address

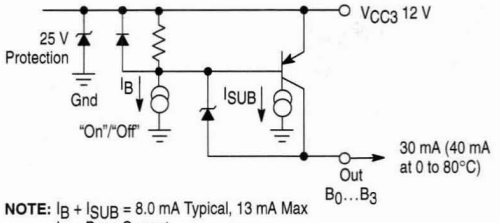
The chip address is programmable by Pin 16 (AS – Address Select).

| AS – Pin 16 | Address (HEX.) |
|---|---|
| Gnd to 0.1 $V_{CC1}$ | C0 |
| Open or 0.2 $V_{CC1}$ to 0.3 $V_{CC1}$ | C2 |
| 0.4 $V_{CC1}$ to 0.7 $V_{CC1}$ | C4 |
| 0.8 $V_{CC1}$ to 1.1 $V_{CC1}$ | C6 |

### Bits $B_0$, $B_1$, $B_2$, $B_3$: Control the Band Buffers

| | |
|---|---|
| $B_0$, $B_1$, $B_2$, $B_3$ = 0 | Buffer "Off" |
| = 1 | Buffer "On" |

**Figure 3. Equivalent Circuit of the Integrated Band Buffers**




**NOTE:** $I_B + I_{SUB}$ = 8.0 mA Typical, 13 mA Max
$I_B$ = Base Current
$I_{SUB}$ = Substrate Current of PNP

### Bit $T_8$: Controls the Output of the Operational Amplifier

| | |
|---|---|
| $T_8$ = 0 | Normal Operation<br>Operational Amplifier Active |
| = 1 | Output State of Operational Amplifier Switched "Off",<br>Output Pulls High Through 20 k Internal Pull–Up Resistor |

### Bits $T_9$, $T_{12}$: Control the Phase Comparator

| $T_9$ | $T_{12}$ | Function |
|---|---|---|
| 1 | 0 | Normal Operation |
| 1 | 1 | High Impedance |
| 0 | 0 | Upper Source "On" Only |
| 0 | 1 | Lower Source "On" Only |

### Bits $T_{10}$, $T_{11}$: Control the Reference Ratio

| $T_{10}$ | $T_{11}$ | Division Ratio |
|---|---|---|
| 0 | 0 | 512 |
| 0 | 1 | 1024 |
| 1 | 0 | 1024 |
| 1 | 1 | 512 |

### Bit $T_{13}$: Switches the Internal Signals $F_{ref}$ and $F_{BY2}$ to the Band Buffer Outputs (Test)

| | |
|---|---|
| $T_{13}$ = 0 | Normal Operation |
| = 1 | Test Mode<br>$F_{ref}$ Output at $B_2$ (Pin 12)<br>$F_{BY2}$ Output at $B_3$ (Pin 13) |

Bits $B_2$ and $B_3$ have to be "On", $B_2 = B_3 = 1$ in the test mode.
$F_{ref}$ is the reference frequency.
$F_{BY2}$ is the output frequency of the programmable divider, divided by two.

9

**Bit $T_{14}$: Controls the Charge Pump Current of the Phase Comparator**

| | |
|---|---|
| $T_{14} = 0$ | Pump Current 15 µA Typical |
| $= 1$ | Pump Current 50 µA Typical |

**The Programmable Divider**

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider; this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8192 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

Minimum Ratio 17

$N_0 \ldots N_{14}$ are the different bits for frequency information.

At power "on" the whole bus receiver is reset and the programmable divider is set to a counting ratio of N = 256 or higher.

**The Prescaler**

The prescaler has a preamplifier which guarantees high input sensitivity.

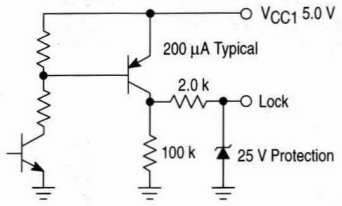
**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**Lock Detector**

The lock detector output is low in lock. The output goes immediately high when an unlock condition is detected. The output goes low again when the loop is in lock during a complete period of the reference frequency.

**Figure 4. Equivalent Circuit of the Lock Output**




**The Operational Amplifier**

The operational amplifier is designed for very low noise, low input bias current and high power supply rejection. The positive input is biased internally. The operational amplifier needs 28.5 V supply ($V_{CC2}$) as minimum voltage for a guaranteed maximum tuning voltage of 28 V.

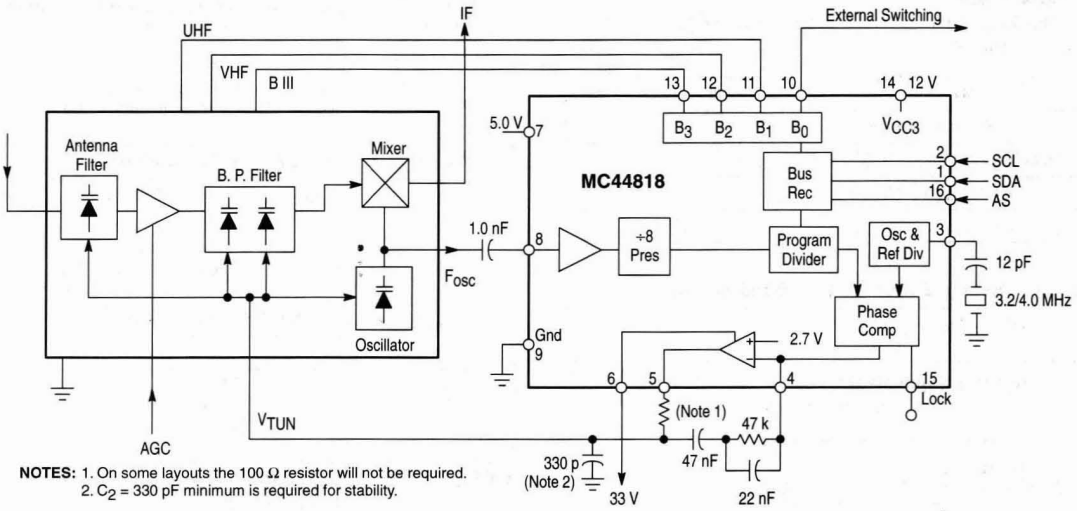
Figure 6 shows a possible filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

**The Oscillator**

The oscillator uses a 3.2 to 4.0 MHz crystal tied to ground in series with a capacitor. The crystal operates in the series resonance mode.

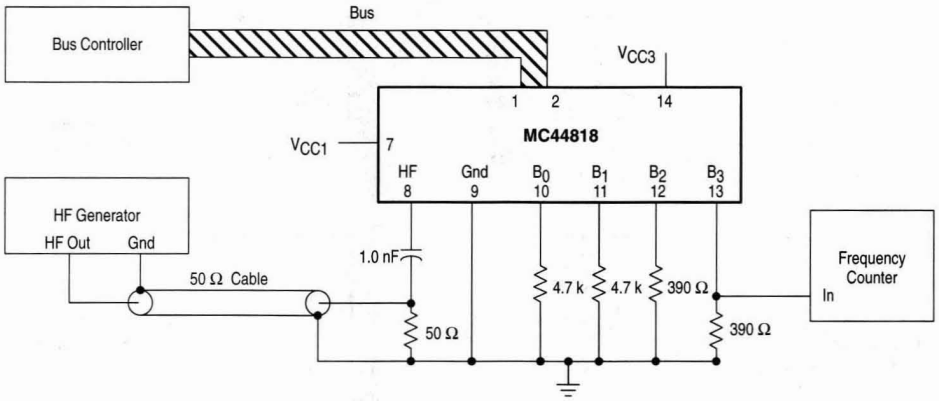
The voltage at Pin 3 has low amplitude and low harmonic distortion.

**Figure 5. Typical Tuner Application**




**NOTES:** 1. On some layouts the 100 Ω resistor will not be required.
2. $C_2$ = 330 pF minimum is required for stability.

**Figure 6. HF Sensitivity Test Circuit**

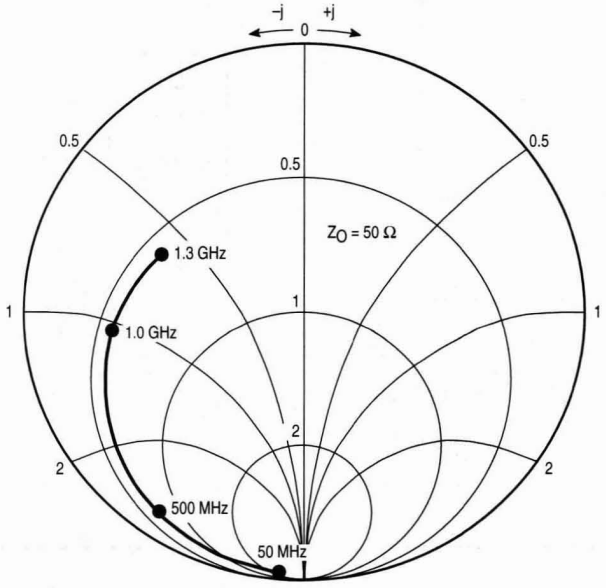



Device is in test mode. $B_2$, $B_3$ are "On" and $B_0$, $B_1$ are "Off".
Sensitivity is level of HF generator on 50 Ω load (without Pin 8 loading).

**HF CHARACTERISTICS** (See Figure 1)

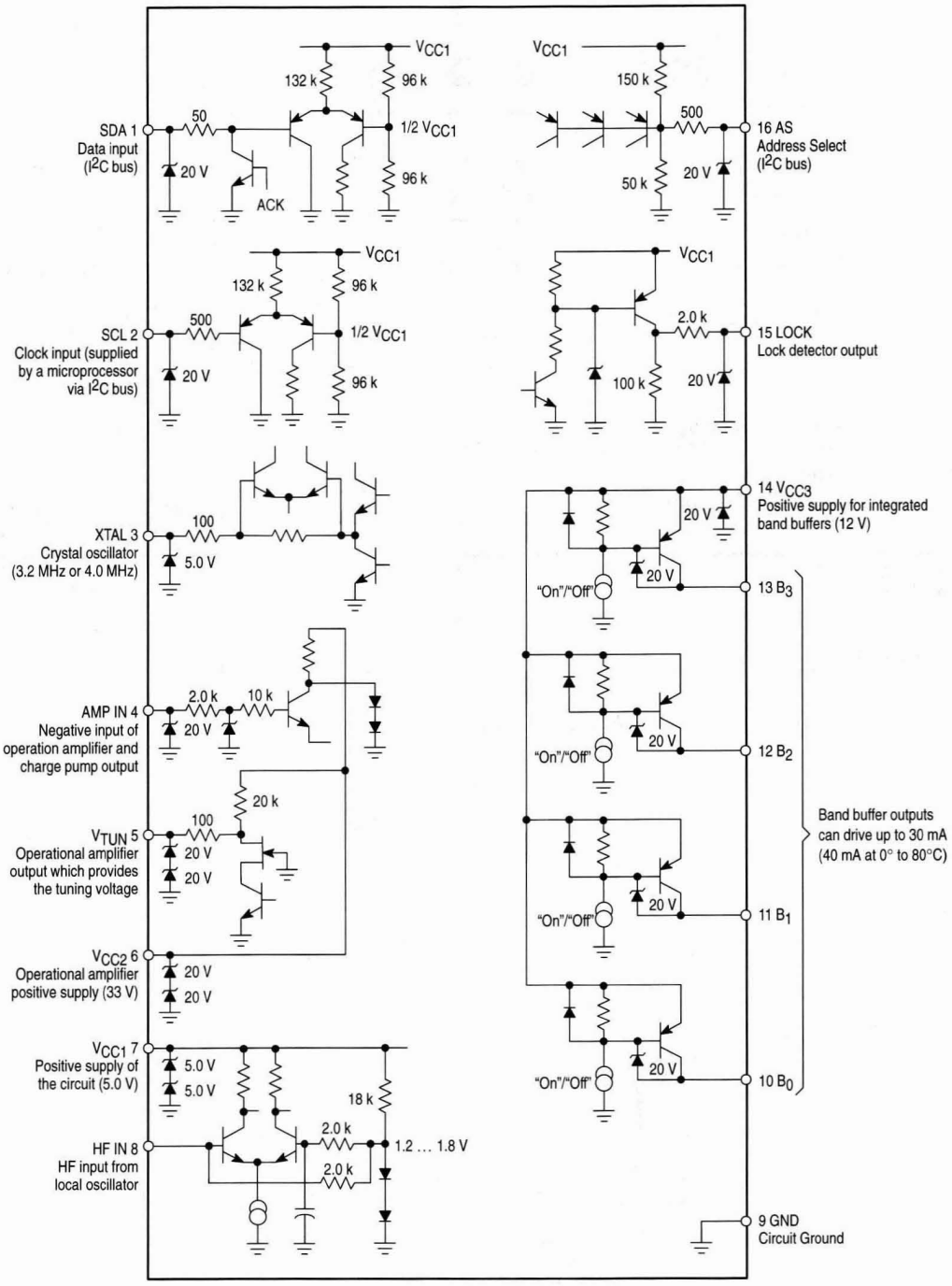
| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| DC Bias | 8 | – | 1.6 | – | V |
| Input Voltage Range | | | | | mVrms |
| 80–150 MHz | 8 | 10 | – | 315 | |
| 150–600 MHz | 8 | 5.0 | – | 315 | |
| 600–950 MHz | 8 | 10 | – | 315 | |
| 950–1300 MHz | 8 | 50 | – | 315 | |

**Figure 7. Typical HF Input Impedance**




9

**Figure 8. Pin Circuit Schematic**



MOTOROLA

# MC44824/25

# PLL Tuning Circuits with I2C Bus

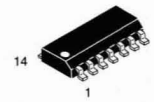
**TV AND VCR PLL TUNING CIRCUITS WITH 1.3 GHz PRESCALER AND I2C BUS**

The MC44824/25 are tuning circuits for TV and VCR tuner applications. They contain on one chip all the functions required for PLL control of a VCO. The integrated circuits also contain a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44824/25 are manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I2C Bus). Data and Clock Inputs are 3–Wire Bus Compatible
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider
- Reference Divider: Programmable for Division Ratios 512 and 1024
- 3–State Phase/Frequency Comparator
- 4 Programmable Chip Addresses
- 3 Output Buffers (MC44824) respectively 5 Output Buffers (MC44825) for 10 mA/15 V
- Operational Amplifier for use with External NPN Transistor
- SO–14 Package for MC44824 and SO–16 for MC44825
- High Sensitivity Preamplifier
- Fully ESD Protected

MOSAIC is a trademark of Motorola, Inc.

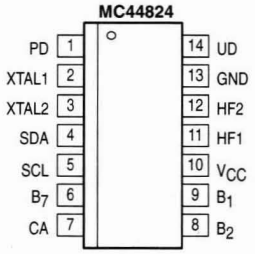



**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**D SUFFIX**
PLASTIC PACKAGE
CASE 751B
(SO–16)

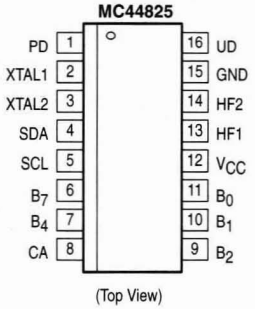
**PIN CONNECTIONS**

**MC44824**




(Top View)

**MC44825**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44824D | $T_A = -20°$ to $+80°C$ | SO–14 |
| MC44825D | | SO–16 |

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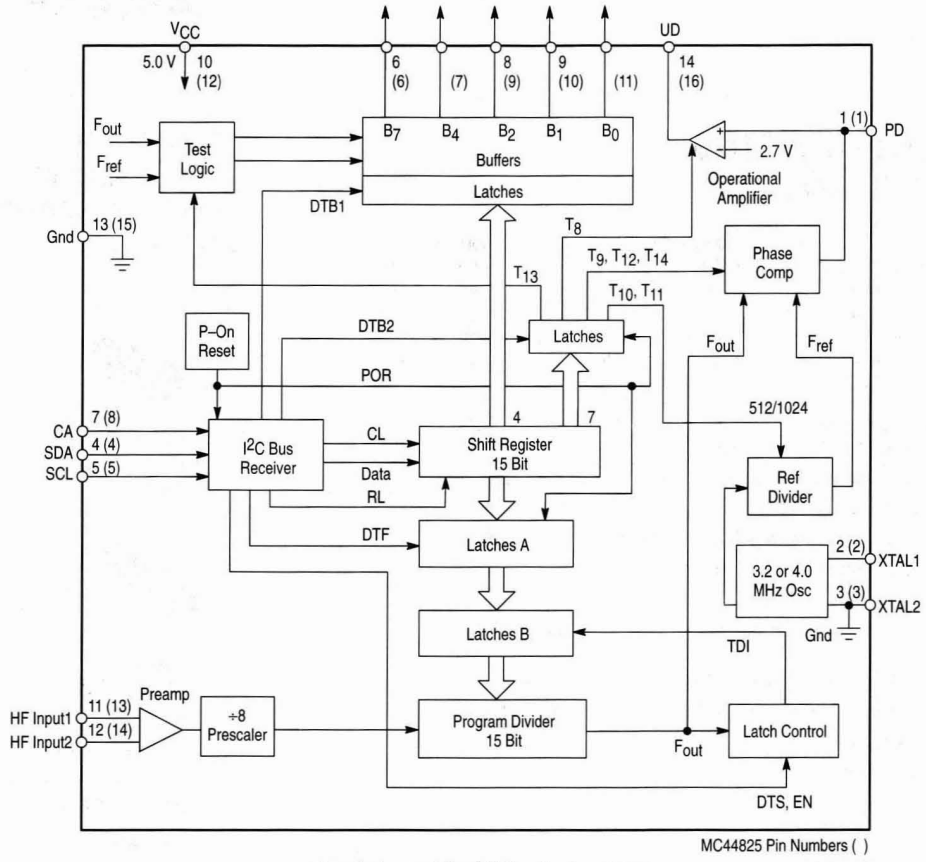
**Representative Block Diagram**




MC44825 Pin Numbers ( )

This device contains 3,204 active transistors.

**PIN FUNCTION DESCRIPTION**

| Pin | | Symbol | Description |
|---|---|---|---|
| MC44824 | MC44825 | | |
| 1 | 1 | PD | Input of tuning voltage amplifier |
| 2 | 2 | XTAL1 | First crystal input is the active pin at the oscillators |
| 3 | 3 | XTAL2 | Second crystal input is the internal ground |
| 4 | 4 | SDA | Data input |
| 5 | 5 | SCL | Clock input of the $I^2C$ bus |
| 6, 8, 9 | – | $B_7$, $B_2$, $B_1$ | Band buffer (open collector) outputs for up to 10 mA |
| – | 6, 7, 9, 10, 11 | $B_7$, $B_4$, $B_2$, $B_1$, $B_0$ | Band buffer (open collector) outputs for up to 10 mA |
| 7 | 8 | CA | Chip address selection pin |
| 10 | 12 | $V_{CC}$ | Supply voltage, typical 5.0 V |
| 11, 12 | 13, 14 | HF1/HF2 | Symmetric HF inputs from local oscillator |
| 13 | 15 | GND | Ground |
| 14 | 16 | UD | Output of the tuning voltage amplifier. Needs an external NPN with pull–up resistor to drive the varicaps |

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin MC44824 | Pin MC44825 | Value | Unit |
|---|---|---|---|---|
| Power Supply Voltage ($V_{CC}$) | 10 | 12 | 6.0 | V |
| Band Buffer "Off" Voltage | 6, 8, 9 | 6, 7, 9, 10, 11 | 15 | V |
| Band Buffer "On" Current | 6, 8, 9 | 6, 7, 9, 10, 11 | 15 | mA |
| Storage Temperature | – | – | −65 to +150 | °C |
| Operating Temperature Range | – | – | −20 to +80 | °C |
| RF Input Level (10 MHz to 1.3 GHz) | 11, 12 | 13, 14 | 1.5 | Vrms |

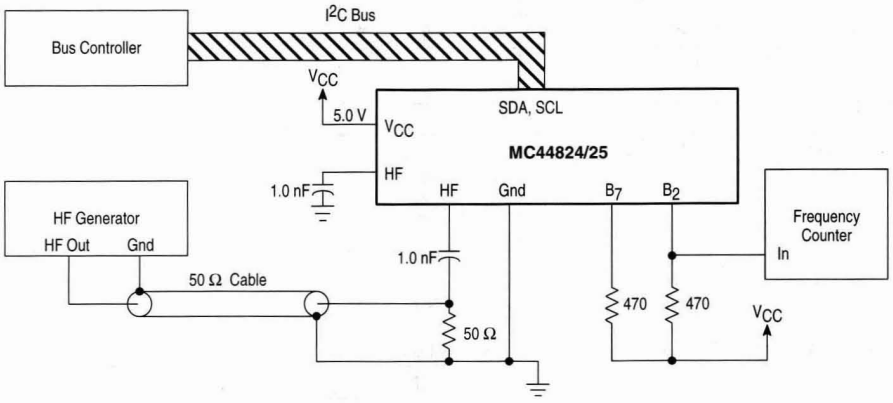
**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 5.0 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin MC44824 | Pin MC44825 | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{CC}$ Supply Voltage Range | 10 | 12 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC}$ Supply Current ($V_{CC}$ = 5.0 V) | 10 | 12 | – | 40 | 55 | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 6, 8, 9 | 6, 7, 9, 10, 11 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 10 mA | 6, 8, 9 | 6, 7, 9, 10, 11 | – | 1.6 | 1.8 | V |
| Data Saturation Voltage at 15 mA Acknowledge "On" | 4 | 4 | – | – | 1.0 | V |
| Data/Clock/Enable Current at 0 V | 4, 5 | 4, 5 | −10 | – | 0 | µA |
| Data/Clock/Enable Current at 5.0 V | 4, 5 | 4, 5 | 0 | – | 1.0 | µA |
| Data/Clock/Enable Input Voltage Low | 4, 5 | 4, 5 | – | – | 1.5 | V |
| Data/Clock/Enable Input Voltage High | 4, 5 | 4, 5 | 3.0 | – | – | V |
| Clock Frequency Range | 5 | 5 | – | – | 100 | kHz |
| Oscillator Frequency Range | 2, 3 | 2, 3 | 3.15 | 3.2 | 4.05 | MHz |
| Operational Amplifier Input Current | 1 | 1 | −15 | 0 | 15 | nA |
| Phase Detector Current in High Impedance State | 1 | 1 | −15 | 0 | 15 | nA |
| Charge Pump Current of Phase Comparator, $T_{14}$ = 0 | 1 | 1 | 30 | 40 | 60 | µA |
| Charge Pump Current of Phase Comparator, $T_{14}$ = 1 | 1 | 1 | 100 | 125 | 200 | µA |

**HF CHARACTERISTICS** (See Figure 1)

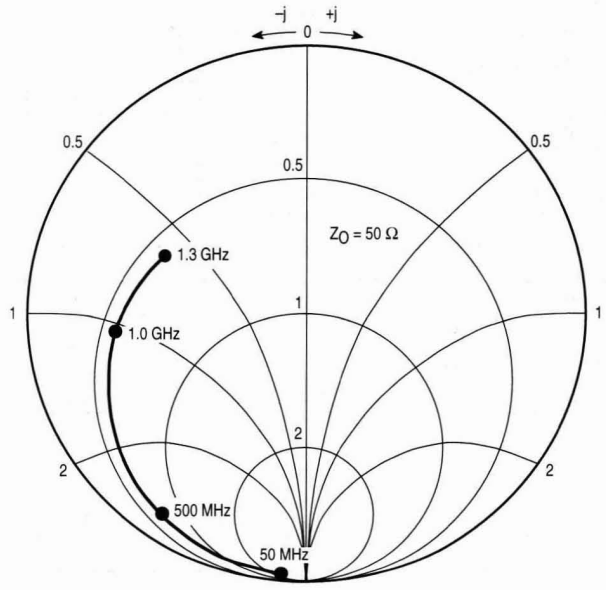
| Characteristic | Pin MC44824 | Pin MC44825 | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| DC Bias | 11, 12 | 13, 14 | – | 1.6 | – | V |
| Input Voltage Range | | | | | | mVrms |
| 80–150 MHz | 11, 12 | 13, 14 | 10 | – | 315 | |
| 150–600 MHz | 11, 12 | 13, 14 | 5.0 | – | 315 | |
| 600–950 MHz | 11, 12 | 13, 14 | 10 | – | 315 | |
| 950–1300 MHz | 11, 12 | 13, 14 | 50 | – | 315 | |

**Figure 1. HF Sensitivity Test Circuit**




Device is in test mode. $B_2$ and $B_7$ are "On".
Sensitivity is level of HF generator on 50 Ω load.

**Figure 2. Typical HF Input Impedance**




9

**Data Format and Bus Receiver**

The circuit receives the information for tuning and control via the I2C bus. The incoming information, consisting of a chip address byte followed by two or four data bytes, is treated in the I2C bus receiver. The definition of the permissible bus protocol is shown below:

1_STA CA CO BA STO
2_STA CA FM FL STO
3_STA CA CO BA FM FL STO
4_STA CA FM FL CO BA STO

STA = Start Condition
STO = Stop Condition
CA = Chip Address Byte
CO = Data Byte for Control Information
BA = Band Information
FM = Data Byte for Frequency Information (MSB's)
FL = Data Byte for Frequency Information (LSB's)

**Figure 3. Complete Data Transfer Process**

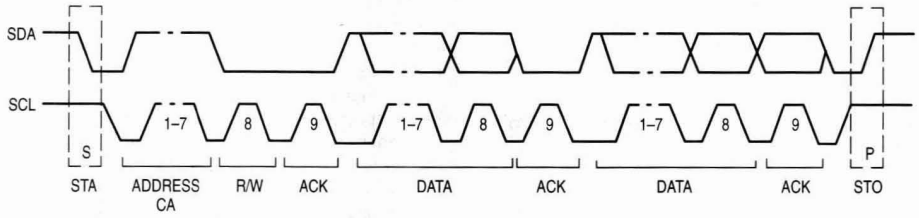



Figure 4 shows the five bytes of information that are needed for circuit operation: there is the chip address, two bytes of control and band information and two bytes of frequency information.

After the chip address, two or four data bytes may be received: if three data bytes are received, the third data byte is ignored.

If five or more data bytes are received, the fifth and following data bytes are ignored and the last acknowledge pulse is sent at the end of the fourth data byte.

The first and the third data bytes contain a function bit which allows the IC to distinguish between frequency information and control plus band information.

Frequency information is preceded by a Logic "0". If the function bit is Logic "1" the two following bytes contain control and band information. The first data byte, shifted after the chip address, may be byte CO or byte FM.

The two permissible bus protocols with five bytes are shown in Figure 4.

**Figure 4. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | $B_7$ | X | X | $B_4$* | X | $B_2$ | $B_1$ | $B_0$* | ACK |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | $B_7$ | X | X | $B_4$* | X | $B_2$ | $B_1$ | $B_0$* | ACK |

* $B_0$ and $B_4$ are only available on MC44825. On MC44824 this data is random.

### Chip Address

The chip address is programmable by Pin 7 (8), CA.

| CA – Pin 7 (8) | Address (HEX.) |
|---|---|
| Gnd to 0.1 $V_{CC1}$ | C0 |
| Open or 0.2 $V_{CC1}$ to 0.3 $V_{CC1}$ | C2 |
| 0.4 $V_{CC1}$ to 0.7 $V_{CC1}$ | C4 |
| 0.8 $V_{CC1}$ to 1.1 $V_{CC1}$ | C6 |

### Bits $B_0$, $B_1$, $B_2$, $B_4$, $B_7$: Control the Band Buffers

| | |
|---|---|
| $B_0$, $B_1$, $B_2$, $B_4$, $B_7$ = 0 | Buffer "Off" |
| = 1 | Buffer "On" |

### Bit $T_8$: Controls the Output of the Operational Amplifier

| | |
|---|---|
| $T_8$ = 0 | Normal Operation<br>Operational Amplifier Active |
| = 1 | Output State of Operational Amplifier Switched "Off",<br>Output Pulls High Through an External Pull–Up Resistor |

### Bits $T_9$, $T_{12}$: Control the Phase Comparator

| $T_9$ | $T_{12}$ | Function |
|---|---|---|
| 1 | 0 | Normal Operation |
| 1 | 1 | High Impedance |
| 0 | 0 | Upper Source "On" Only |
| 0 | 1 | Lower Source "On" Only |

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**Bits $T_{10}$, $T_{11}$: Control the Reference Ratio**

| $T_{10}$ | $T_{11}$ | Division Ratio |
|---|---|---|
| 0 | 0 | 512 |
| 0 | 1 | 1024 |
| 1 | 0 | 1024 |
| 1 | 1 | 512 |

**Bit $T_{13}$: Switches the Internal Signals $F_{ref}$ and $F_{BY2}$ to the Band Buffer Outputs (Test)**

| | |
|---|---|
| $T_{13}$ = 0 | Normal Operation |
| = 1 | Test Mode<br>$F_{ref}$ Output at $B_7$<br>$F_{BY2}$ Output at $B_2$ |

Bits $B_2$ and $B_7$ have to be "Off", $B_2 = B_7 = 0$ in the test mode.
$F_{ref}$ is the reference frequency.
$F_{BY2}$ is the output frequency of the programmable divider, divided by two.

**Bit $T_{14}$: Controls the Charge Pump Current of the Phase Comparator**

| | |
|---|---|
| $T_{14}$ = 0 | Pump Current 40 µA Typical |
| = 1 | Pump Current 125 µA Typical |

**The Band Buffers**

**BA_Band Information**
**MC44824 14 Pin version**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $B_7$ | X | X | X | X | $B_2$ | $B_1$ | X | ACK |

**MC44825 16 Pin version**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $B_7$ | X | X | $B_4$ | X | $B_2$ | $B_1$ | $B_0$ | ACK |

The band buffers are open collector buffers and are active "low" at Bn = 1. They are designed for 10 mA with a typical "On" resistance of 160 Ω. These buffers are designed to withstand relative high output voltage in the "Off" state.

$B_2$ and $B_7$ buffers may also be used to output internal IC signals (reference frequency and programmable divider output frequency divided by 2) for test purposes.

The bit $B_2$ and/or $B_7$ have to be zero if the buffers are used for these additional functions.

**The Programmable Divider**

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider, this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8192 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

Minimum Ratio 17

Where $N_0$ ... $N_{14}$ are the different bits for frequency information.

The counter may be used for any ratio between 17 and 32767 and reloads correctly as long as its output frequency does not exceed 1.0 MHz.

The data transfer between latches A and B (signal TDI) is also initiated by any start condition on the $I^2C$ bus.

At power–on, the whole bus receiver is reset and the programmable divider is set to a counting ration of N = 256 or higher.

The first $I^2C$ message must be sent only when the POWER ON RESET is completed.

**The Prescaler**

The prescaler has a preamplifier which guarantees high input sensitivity.

**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**The Tuning Voltage Amplifier**

The amplifier is designed for very low noise, low input bias current and high power supply rejection. The positive input is biased internally. The tuning voltage amplifier needs an external NPN with a pull–up resistor to generate the tuning voltage.

The amplifier can be switched "Off" through bit $T_8$. When bit $T_8$ is "One", the amplifier is "Off". The tuning voltage is then pulled high by the external pull–up resistor.

Figure 5 shows a possible filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

As a starting point for optimization, the component values in Figure 5 may be used for 7.8125 kHz reference frequency in a multiband TV tuner.

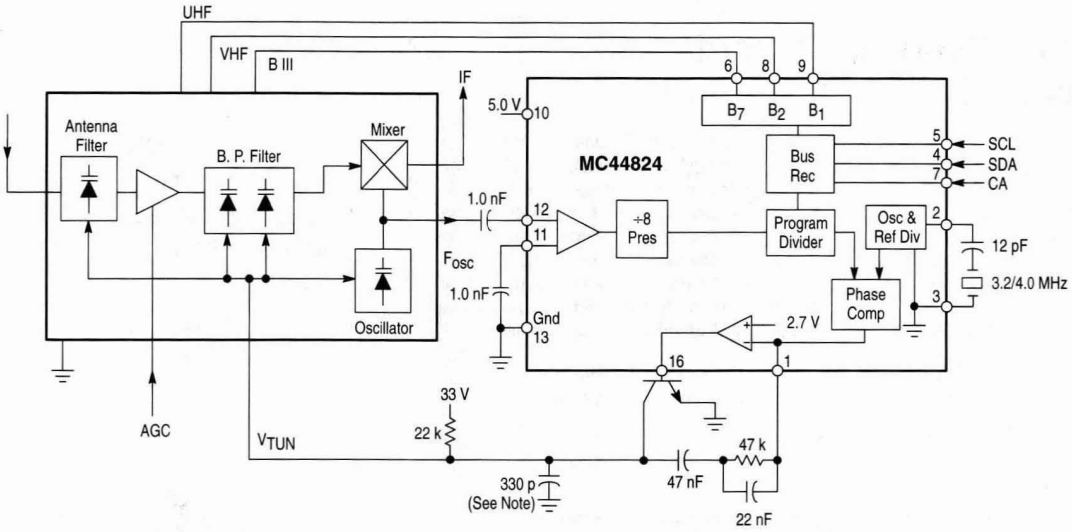
**The Oscillator**

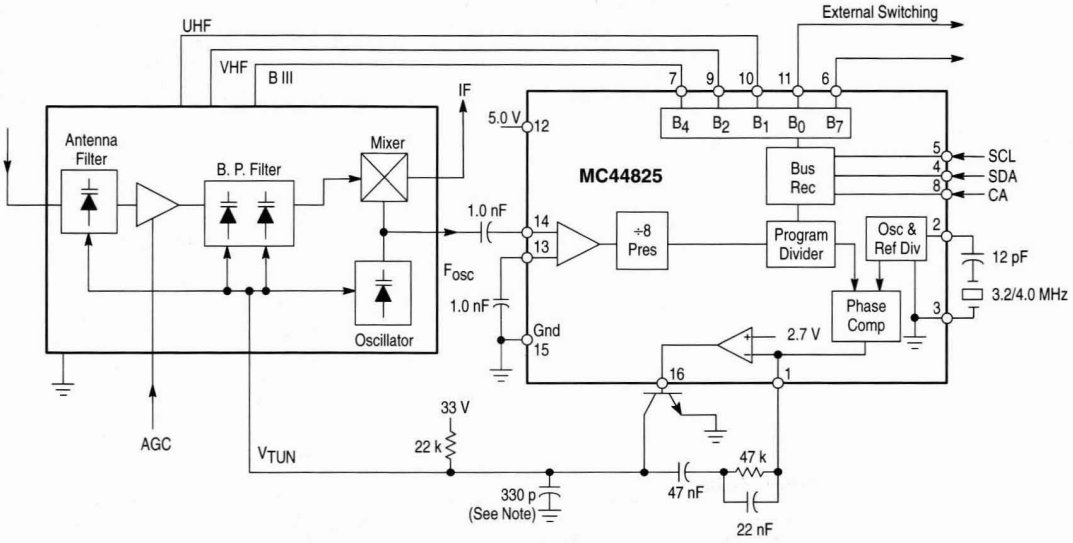
The oscillator uses a 4.0 MHz crystal tied to ground "or between Pins 2 and 3" through a series capacitor. The crystal oscillates in its series resonance mode.

The voltage at Pin 13 XTAL1, has low amplitude and low harmonic distortion.

Pin XTAL2 is the internal ground of the oscillator; it is connected internally to ground Pin 13 (15).

**Figure 5. Typical Tuner Applications**




**NOTE:** $C_2$ = 330 pF minimum is required for stability.

9

MOTOROLA

# MC44826

# PLL Tuning Circuit with I2C Bus

The MC44826 is a tuning circuit for TV and VCR tuner applications. It contains, on one chip, all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz. The circuit has a band decoder that provides the band switching signal for the mixer/oscillator circuit. The decoder is controlled by the buffer bits or independently by extra bits $T_6$ and $T_7$.

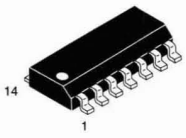
The MC44826 has a programmable 512/1024 reference divider and is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I2C Bus)
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider
- Reference Divider: Programmable for Division Ratios 512 and 1024
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Programmable Chip Addresses
- Integrated Band Decoder for the Mixer/Oscillator Circuit
- Band Buffers with Low "On" Voltage (0.4 V Maximum at 15 mA)
- Fully ESD Protected to MIL–STD–883C, Method 3015.7 (2000 V, 1.5 kΩ, 150 pF)

MOSAIC is a trademark of Motorola, Inc.

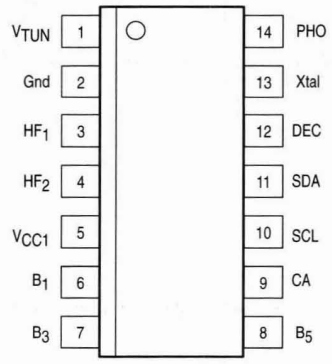
**TV AND VCR I2C PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND MIX/OSC DECODER**

**SEMICONDUCTOR TECHNICAL DATA**




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44826D | $T_A$ = –20° to +80°C | SO–14 |

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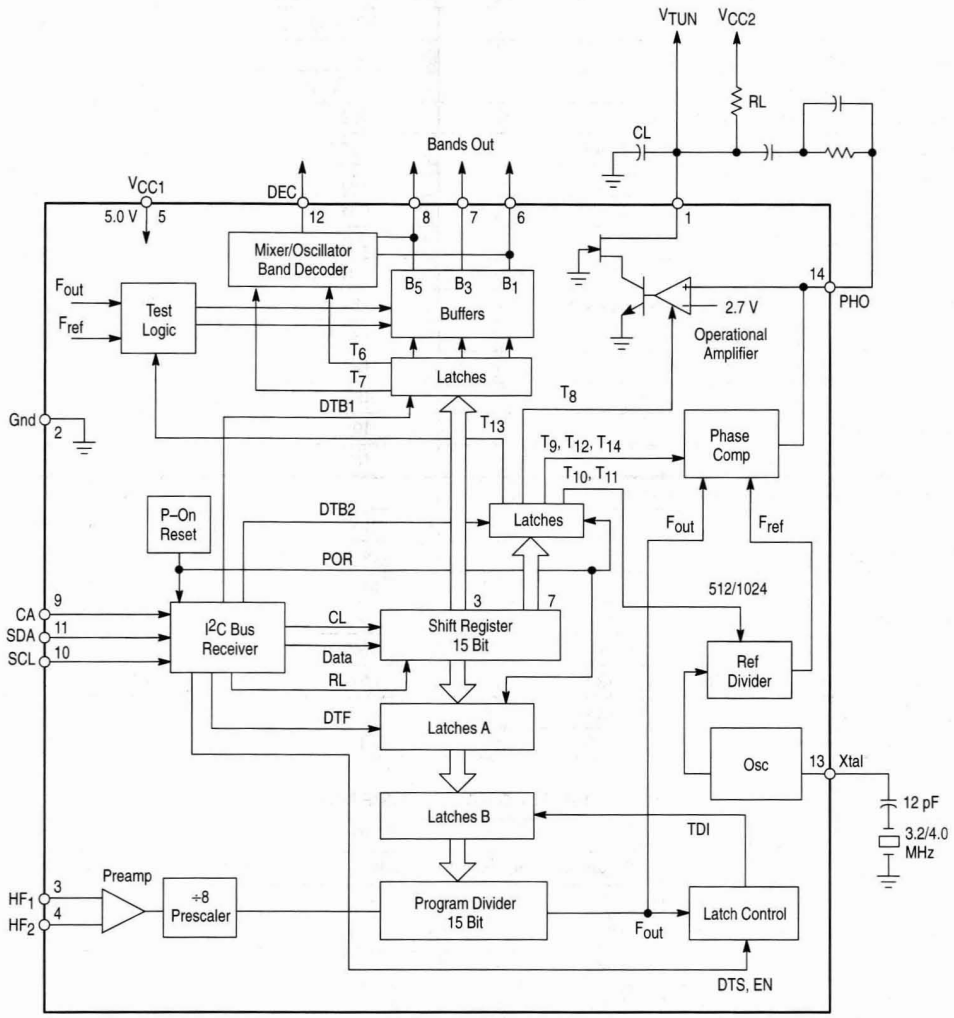
### Representative Block Diagram




This device contains 3,204 active transistors.

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage ($V_{CC1}$) | 5 | 6.0 | V |
| Band Buffer "Off" Voltage | 6, 7, 8 | 15 | V |
| Band Buffer "On" Current | 6, 7, 8 | 20 | mA |
| Operational Amplifier Power Supply ($V_{CC2}$) | 1 | 40 | V |
| RF Input Level 10 MHz to 1.3 GHz | 3, 4 | 1.5 | Vrms |
| Storage Temperature | – | –65 to +150 | °C |
| Operating Temperature Range | – | –20 to +80 | °C |
| Bus Input Voltage (Positive) | 10, 11 | 7 | V |
| Bus Input Voltage (Negative) | 10, 11 | –0.5 | V |

**ELECTRICAL CHARACTERISTICS** ($V_{CC1}$ = 5.0 V, $V_{CC2}$ = 33 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $V_{CC1}$ Supply Voltage Range | 5 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC1}$ Supply Current ($V_{CC1}$ = 5.0 V) | 5 | 25 | 35 | 50 | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 6, 7, 8 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 15 mA | 6, 7, 8 | – | 0.2 | 0.4 | V |
| Data/Clock Current at 0 V (Acknowledge "Off") | 10, 11 | –10 | – | 0 | µA |
| Data/Clock Current at 5.0 V (Acknowledge "Off") | 10, 11 | 0 | – | 1.0 | µA |
| Data/Clock Input Voltage Low | 10, 11 | – | – | 1.5 | V |
| Data/Clock Input Voltage High | 10, 11 | 3.0 | – | – | V |
| Data Saturation Voltage at 3.0 mA (Acknowledge "On") | 11 | – | 0.25 | 0.4 | V |
| Decoder "High" Level Sourcing 100 µA | 12 | 3.4 | – | $V_{CC1}$ | V |
| Decoder "Medium" Level Sourcing 15 µA | 12 | 1.7 | – | 2.3 | V |
| Decoder "Low" Level Sinking 20 µA | 12 | 0 | – | 0.8 | V |
| Clock Frequency Range | 10 | – | – | 100 | kHz |
| Oscillator Frequency Range | 13 | 3.15 | 3.2 | 4.05 | MHz |
| Operational Amplifier Internal Reference Voltage | – | 2.0 | 2.75 | 3.2 | V |
| Operational Amplifier Input Current | 14 | –15 | 0 | 15 | nA |
| DC Open Loop Gain ($R_L$ = 22 kΩ) | 14, 1 | 100 | 250 | 1000 | V/V |
| Gain Bandwidth Product ($C_L$ = 0.5 nF) | 14, 1 | 0.3 | – | – | MHz |
| $V_{out}$ Low ($R_L$ = 22 kΩ) | 1 | – | 0.25 | 0.4 | V |
| Phase Detector Current in High Impedance State | 14 | –15 | 0 | 15 | nA |
| Charge Pump Current of Phase Comparator ($T_{14}$ = 0) | 14 | 30 | 40 | 50 | µA |
| Charge Pump Current of Phase Comparator ($T_{14}$ = 1) | 14 | 90 | 125 | 150 | µA |
| $V_{CC2}$ Supply Voltage Range | 1 | 25 | 33 | 36 | V |

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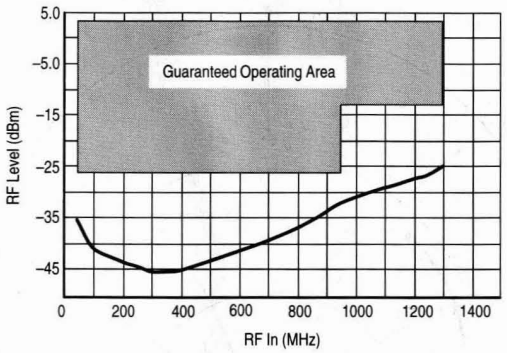
**PIN FUNCTION DESCRIPTION**

| Pin | Function | Description |
|---|---|---|
| 1 | $V_{TUN}/V_{CC2}$ | Output of the tuning voltage amplifier. Needs an external pull–up resistor to drive the varicaps |
| 2 | Gnd | Ground |
| 3, 4 | $HF_1$/ $HF_2$ | Symmetric HF inputs from local oscillator |
| 5 | $V_{CC1}$ | Supply voltage. Typical 5.0 V |
| 6, 7, 8 | $B_1$, $B_3$, $B_5$ | Band buffer outputs |
| 9 | CA | Chip address selection pin |
| 10 | SCL | Clock input of the $I^2C$ bus |
| 11 | SDA | Data input |
| 12 | DEC | Band decoder output for the mixer/oscillator circuit |
| 13 | Xtal | Crystal input |
| 14 | PHO | Input of tuning voltage amplifier |

**Figure 1. Typical Prescaler Input Sensitivity**

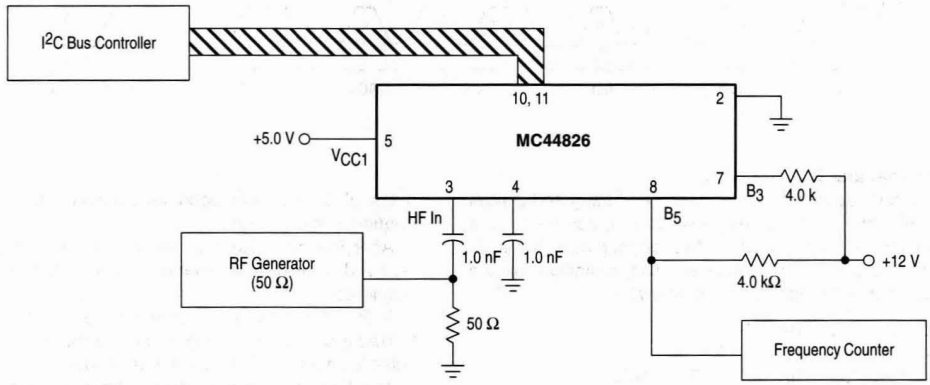



**NOTE:** $V_{CC}$ = 4.5 to 5.5 V, $T_A$ = – 20° to +80°C

**HF CHARACTERISTICS** (See Figure 1)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| DC Bias | 3, 4 | – | 1.6 | – | V |
| Input Voltage Range | | | | | mVrms |
| 50–950 MHz | 3, 4 | 10 | – | 315 | |
| 950–1300 MHz | 3, 4 | 50 | – | 315 | |

**Figure 2. RF Sensitivity Test Circuit**




Device is in test mode, $B_5$ and $B_3$ are "On", $B_1$ is "Off".
Sensitivity is the level of the HF generator on 50 Ω load.

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**Figure 3. Typical HF Input Impedance**

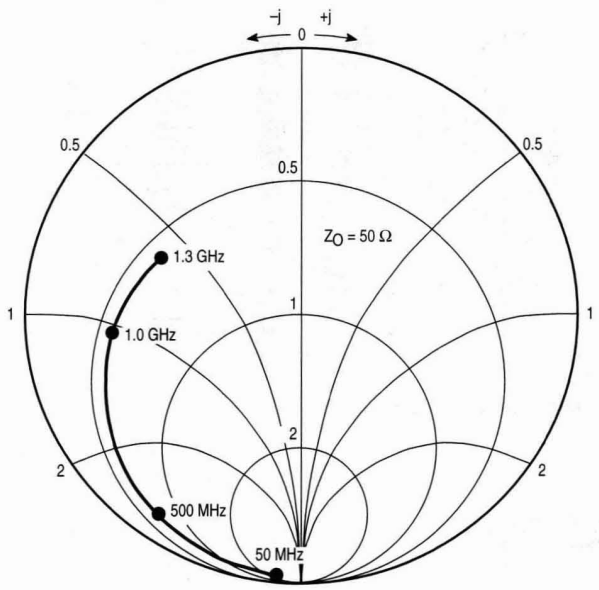
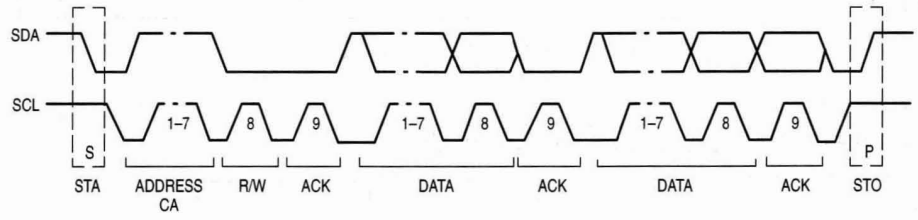



**Figure 4. Complete Data Transfer Process**




9

**Data Format and Bus Receiver**

The circuit receives the information for tuning and control via the I²C bus. The incoming information, consisting of a chip address byte followed by two or four data bytes, is treated in the I²C bus receiver. The definition of the permissible bus protocol is shown below:

| | | | | | | |
|---|---|---|---|---|---|---|
| 1_STA | CA | CO | BA | STO | | |
| 2_STA | CA | FM | FL | STO | | |
| 3_STA | CA | CO | BA | FM | FL | STO |
| 4_STA | CA | FM | FL | CO | BA | STO |

STA = Start Condition
STO = Stop Condition
CA = Chip Address Byte
CO = Data Byte for Control Information
BA = Band Information
FM = Data Byte for Frequency Information (MSB's)
FL = Data Byte for Frequency Information (LSB's)

Figure 5 shows the five bytes of information that are needed for circuit operation: there is the chip address, two bytes of control and band information and two bytes of frequency information.

After the chip address, two or four data bytes may be received: if three data bytes are received the third data byte is ignored.

If five or more data bytes are received the fifth and following data bytes are ignored and the last acknowledge pulse is sent at the end of the fourth data byte.

The first and the third data bytes contain a function bit which allows the IC to distinguish between frequency information and control plus band information.

Frequency information is preceded by a Logic "0". If the function bit is Logic "1" the two following bytes contain control and band information. The first data byte, shifted after the chip address, may be byte CO or byte FM.

The two permissible bus protocols with five bytes are shown in Figure 5.

The Data and Clock inputs (Pins 10 and 11) are high impedance when the supply voltage $V_{CC1}$ is between 0 and 5.5 V.

### Chip Address

The chip address is programmable by Pin 9 (CA – Address Select).

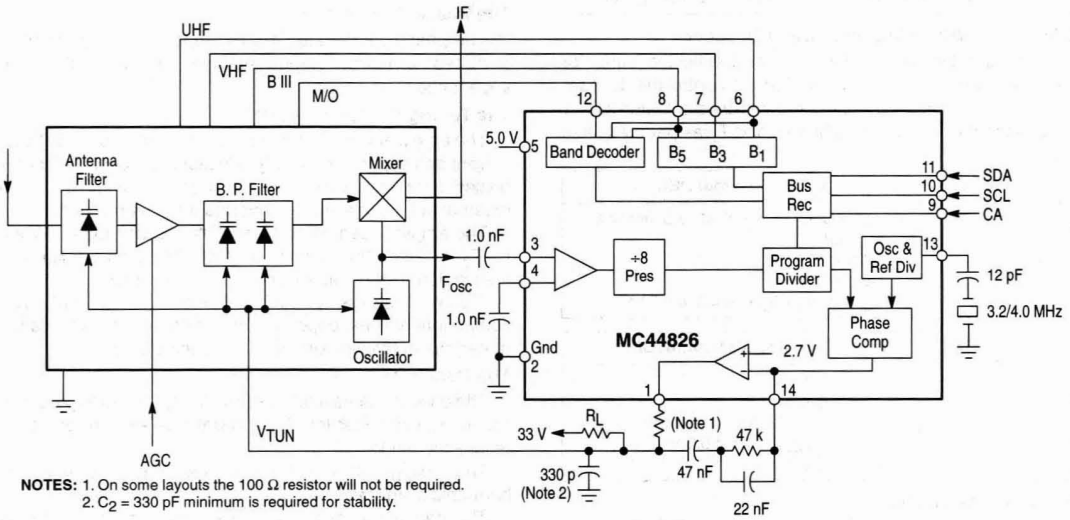
| CA – Pin 9 | Address (HEX.) |
|---|---|
| –0.04 $V_{CC1}$ to 0.1 $V_{CC1}$ | C6 |
| Open or 0.2 $V_{CC1}$ to 0.3 $V_{CC1}$ | C4 |
| 0.42 $V_{CC1}$ to 0.75 $V_{CC1}$ | C2 |
| 0.9 $V_{CC1}$ to 1.2 $V_{CC1}$ | C0 |

**Figure 5. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| | | | | | | | | | |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | $T_7$ | $T_6$ | $B_5$ | X | $B_3$ | X | $B_1$ | X | ACK |
| | | | | | | | | | |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| | | | | | | | | | |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |
| | | | | | | | | | |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | $T_7$ | $T_6$ | $B_5$ | X | $B_3$ | X | $B_1$ | X | ACK |

**Figure 6. Typical Tuner Application**




**NOTES:** 1. On some layouts the 100 Ω resistor will not be required.
2. $C_2$ = 330 pF minimum is required for stability.

**Bits $B_1$, $B_3$, $B_5$: Control the Band Buffers**

| | |
|---|---|
| $B_1$, $B_3$, $B_5$ = 0 | Buffer "Off" |
| = 1 | Buffer "On" |

**Bit $T_8$: Controls the Output of the Operational Amplifier**

| | |
|---|---|
| $T_8$ = 0 | Normal Operation<br>Operational Amplifier Active |
| = 1 | Output State of Operational Amplifier Switched "Off",<br>Output Pulls High Through the External Pull–Up Resistor $R_L$ |

**Bits $T_9$, $T_{12}$: Control the Phase Comparator**

| $T_9$ | $T_{12}$ | Function |
|---|---|---|
| 1 | 0 | Normal Operation |
| 1 | 1 | High Impedance |
| 0 | 0 | Upper Source "On" Only |
| 0 | 1 | Lower Source "On" Only |

**Bits $T_{10}$, $T_{11}$: Control the Reference Divider**

| $T_{10}$ | $T_{11}$ | Division Ratio |
|---|---|---|
| 0 | 0 | 512 |
| 0 | 1 | 1024 |
| 1 | 0 | 1024 |
| 1 | 1 | 512 |

**Bit $T_{13}$: Switches the Internal Signals $F_{ref}$ and $F_{BY2}$ to the Band Buffer Outputs (Test)**

| | |
|---|---|
| $T_{13}$ = 0 | Normal Operation |
| = 1 | Test Mode<br>$F_{ref}$ Output at $B_3$ (Pin 7)<br>$F_{BY2}$ Output at $B_5$ (Pin 8) |

Bits $B_3$ and $B_5$ have to be "On", $B_3 = B_5 = 1$ in the test mode.
$F_{ref}$ is the reference frequency.
$F_{BY2}$ is the output frequency of the programmable divider, divided by two.

**Bit $T_{14}$: Controls the Charge Pump Current of the Phase Comparator**

| | |
|---|---|
| $T_{14}$ = 0 | Pump Current 40 µA Typical |
| = 1 | Normal Operation. Pump Current 125 µA Typical |

**Bits $T_6$, $T_7$: Mixer/Oscillator Band Decoder**

The band decoder provides the band switching signal for the mixer/oscillator circuit. The buffer bits control the decoder output. The decoder can be controlled by the buffer bits or independently by the control bits $T_6$ and $T_7$ as per the tables below.

| $T_7$ | $T_6$ | Decoder Output DEC |
|---|---|---|
| 0 | 0 | Decoder Output Controlled by Buffer Bits $B_1$, $B_3$, $B_5$ |
| 0 | 1 | 0 to 0.8 V |
| 1 | 0 | 1.8 to 2.1 V |
| 1 | 1 | 3.4 V to $V_{CC1}$ ($V_{CC1}$ = 4.5 to 5.5 V) |

| $B_5$ | $B_3$ | $B_1$ | Decoder Output DEC |
|---|---|---|---|
| 0 | X | 0 | 1.8 to 2.1 V |
| 0 | X | 1 | 0 to 0.8 V |
| 1 | X | 0 | 3.4 V to $V_{CC1}$ ($V_{CC1}$ = 4.5 to 5.5 V) |
| 1 | X | 1 | Undefined |

**BA_Band Information**

| $T_7$ | $T_6$ | $B_5$ | X | $B_3$ | X | $B_1$ | X | ACK |
|---|---|---|---|---|---|---|---|---|

The band buffers are open collector buffers and are active "low" at Bn = 1. They are designed for 15 mA with a typical "On" voltage of 200 mV. These buffers are designed to withstand relative high output voltage in the "Off" state.

$B_3$ and $B_5$ buffers may also be used to output internal IC signals (reference frequency and programmable divider output frequency divided by 2) for test purposes.

The bit $B_3$ and/or $B_5$ have to be one if the buffers are used for these additional functions.

**The Programmable Divider**

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider, this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8192 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

Minimum Ratio 256

Where $N_0$ ... $N_{14}$ are the different bits for frequency information.

The counter may be used for any ratio between 256 and 32767, and reloads correctly as long as its output frequency does not exceed 1.0 MHz.

The data transfer between latches A and B (signal TDI) is also initiated by any start condition on the $I^2C$ bus.

At power–on the whole bus receiver is reset and the bit $N_8$ of the programmable divider is set to $N_8$ = 1. Thus the programmable divider starts with a division ratio of 256 or higher.

The first $I^2C$ message must be sent only when the POWER ON RESET is completed. Division ratios of N < 256 are not allowed.

**The Prescaler**

The prescaler has a preamplifier which guarantees high input sensitivity.

**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**The Tuning Voltage Amplifier**

The amplifier is designed for very low noise, low input bias current and high power supply rejection. The positive input is biased internally. The tuning voltage amplifier needs an external pull–up resistor to generate the tuning voltage.

The amplifier can be switched "Off" through bit $T_8$. When bit $T_8$ is "One", the amplifier is "Off". The tuning voltage is then pulled high by the external pull–up resistor.

Figure 6 shows a possible filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

**The Oscillator**

The oscillator uses a 3.2 or 4.0 MHz crystal tied to ground in series with a capacitor. The crystal operates in its series resonance mode.

The voltage at Pin 13, has low amplitude and low harmonic distortion.

The negative impedance of the crystal input (Pin 13) is about 3.0 kΩ.

MOTOROLA

# MC44827

*Product Preview*

## PLL Tuning Circuit with 3-Wire Bus

The MC44827 is a tuning circuit for TV and VCR tuner applications. This device contains on one chip all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44827 is controlled by a 3–wire bus. It has the same function as the MC44828 which is $I^2C$ bus controlled. The MC44827 and MC44828 can replace each other to allow conversion between 3–wire bus and $I^2C$ bus control.

The MC44827 is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

The MC44827 has the same features as MC44817 with the following differences:

- Lower Power Consumption, 200 mW Typical
- Improved Prescaler with Higher Margins for Sensitivity and Temperature Range. (A typical device is functional in a temperature range greater than –40 to 100°C.)
- Lock Detector with Push–Pull Output
- No Bypass of Divide–by–8 Prescaler
- TSSOP Package

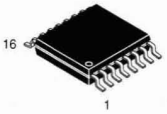
MOSAIC is a trademark of Motorola, Inc.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44827DTB | $T_J$ = –20 ° to +80°C | 16 Pin TSSOP |

**PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND 3–WIRE BUS**

**SEMICONDUCTOR TECHNICAL DATA**

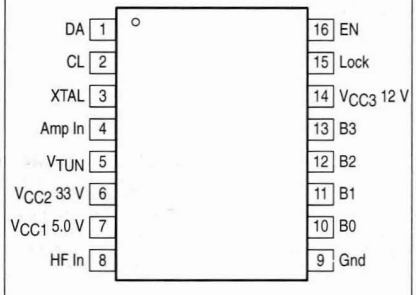



**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948F
(TSSOP–16)

9

**PIN CONNECTIONS**

**16 Pin TSSOP**




(Top View)

MOTOROLA

# MC44828

*Product Preview*

## PLL Tuning Circuit with I2C Bus

The MC44828 is a tuning circuit for TV and VCR tuner applications. This device contains on one chip all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz.

The MC44828 is controlled by an I2C bus. It has the same function as the MC44827 which is 3–wire bus controlled. The MC44827 and MC44828 can replace each other to allow conversion between 3–wire bus and I2C bus control.

The MC44828 is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

The MC44828 has the same features as MC44818 with the following differences:

- Lower Power Consumption, 200 mW Typical
- Improved Prescaler with Higher Margins for Sensitivity and Temperature Range. (A typical device is functional in a temperature range greater than –40 to 100°C.)
- Lock Detector with Push–Pull Output
- TSSOP Package

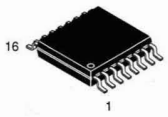
MOSAIC is a trademark of Motorola, Inc.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44828DTB | $T_J$ = –20 ° to +80°C | 16 Pin TSSOP |

**PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND I2C BUS**

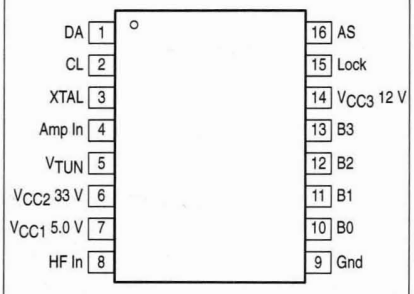
**SEMICONDUCTOR TECHNICAL DATA**




**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948F
(TSSOP–16)

**PIN CONNECTIONS**

**16 Pin TSSOP**




(Top View)

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MOTOROLA

# MC44829

# PLL Tuning Circuit with I2C Bus

The MC44829 is a tuning circuit for TV and VCR tuner applications. It contains, on one chip, all the functions required for PLL control of a VCO. This integrated circuit also contains a high frequency prescaler and thus can handle frequencies up to 1.3 GHz. The circuit has a band decoder that provides the band switching signal for the mixer/oscillator circuit. The decoder is controlled by the buffer bits.

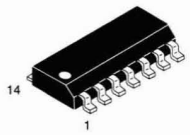
The MC44829 has programmable 512/1024 reference dividers and is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSAIC™ (Motorola Oxide Self Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control (I2C Bus)
- Divide–by–8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider
- Reference Divider: Programmable for Division Ratios 512 and 1024
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Tuning Voltage Output (30 V)
- Four Programmable Chip Addresses
- Integrated Band Decoder for the Mixer/Oscillator Circuit
- Band Buffers with Low "On" Voltage (0.4 V Maximum at 5.0 mA)
- Fully ESD Protected to MIL–STD–883C, Method 3015.7 (2000 V, 1.5 kΩ, 150 pF)

MOSAIC is a trademark of Motorola, Inc.

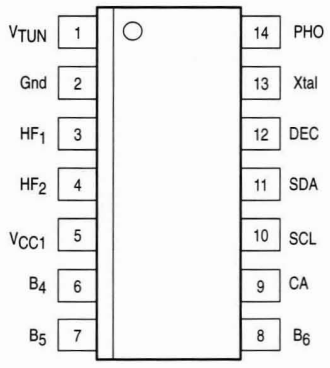
**TV AND VCR I2C PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND MIX/OSC DECODER**

**SEMICONDUCTOR TECHNICAL DATA**




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**PIN CONNECTIONS**




(Top View)

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage ($V_{CC1}$) | 5 | 6.0 | V |
| Band Buffer "Off" Voltage | 6, 7, 8 | 15 | V |
| Band Buffer "On" Current | 6, 7, 8 | 10 | mA |
| Operational Amplifier Power Supply ($V_{CC2}$) | 1 | 40 | V |
| RF Input Level 10 MHz to 1.3 GHz | 3, 4 | 1.5 | Vrms |
| Storage Temperature | – | –65 to +150 | °C |
| Operating Temperature Range | – | –20 to +80 | °C |
| Bus Input Voltage (Positive) | 10, 11 | 7.0 | V |
| Bus Input Voltage (Negative) | 10, 11 | –0.5 | V |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44829D | $T_A$ = –20° to +80°C | SO–14 |

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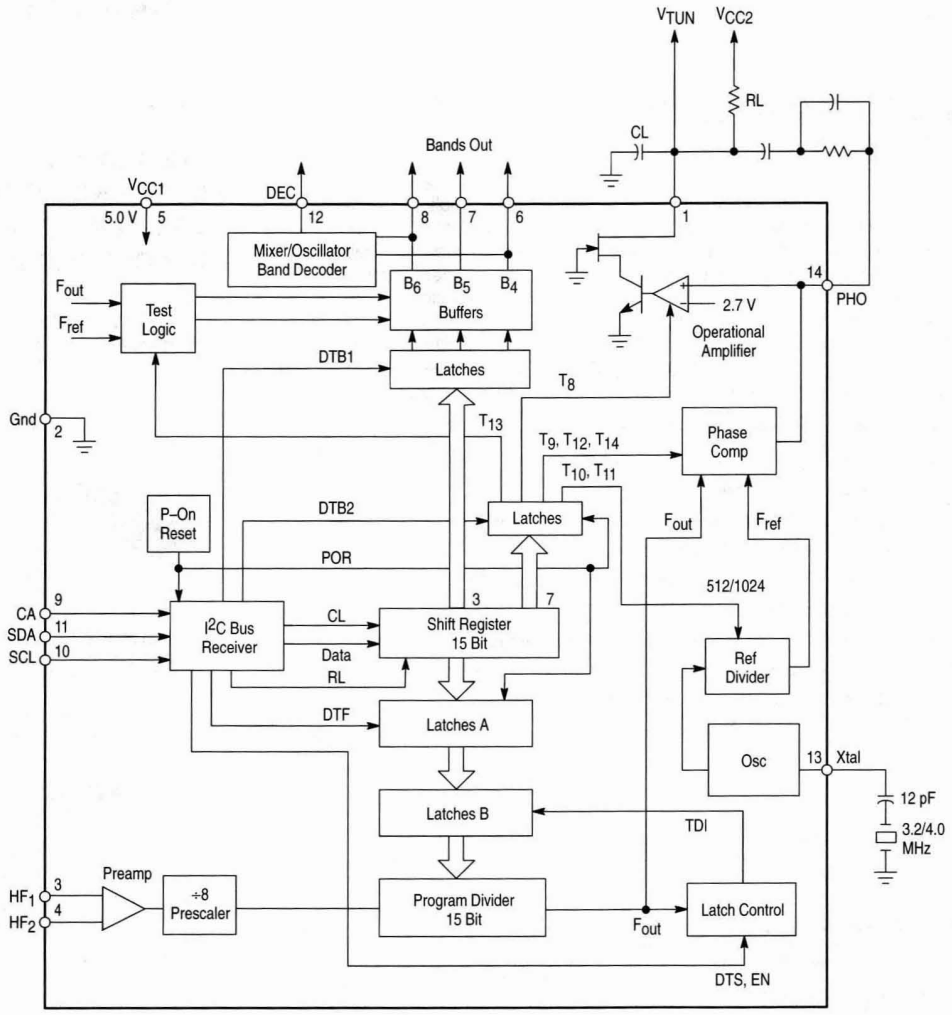
**Representative Block Diagram**




This device contains 3,204 active transistors.

**ELECTRICAL CHARACTERISTICS** ($V_{CC1}$ = 5.0 V, $V_{CC2}$ = 33 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $V_{CC1}$ Supply Voltage Range | 5 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC1}$ Supply Current ($V_{CC1}$ = 5.0 V) | 5 | 25 | 35 | 50 | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 6, 7, 8 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 5.0 mA | 6, 7, 8 | – | 0.16 | 0.4 | V |
| Data/Clock Current at 0 V (Acknowledge "Off") | 10, 11 | –10 | – | 0 | µA |
| Data/Clock Current at 5.0 V (Acknowledge "Off") | 10, 11 | 0 | – | 1.0 | µA |
| Data/Clock Input Voltage Low | 10, 11 | – | – | 1.5 | V |
| Data/Clock Input Voltage High | 10, 11 | 3.0 | – | – | V |
| Data Saturation Voltage at 3.0 mA (Acknowledge "On") | 11 | – | 0.25 | 0.4 | V |
| Decoder "High" Level Sourcing 100 µA | 12 | 3.4 | – | $V_{CC1}$ | V |
| Decoder "Medium" Level Sourcing 15 µA | 12 | 1.8 | – | 2.1 | V |
| Decoder "Low" Level Sinking 20 µA | 12 | 0 | – | 0.8 | V |
| Clock Frequency Range | 10 | – | – | 100 | kHz |
| Oscillator Frequency Range | 13 | 3.15 | 3.2 | 4.05 | MHz |
| Operational Amplifier Internal Reference Voltage | – | 2.0 | 2.75 | 3.2 | V |
| Operational Amplifier Input Current | 14 | –15 | 0 | 15 | nA |
| DC Open Loop Gain ($R_L$ = 22 kΩ) | 14, 1 | 100 | 250 | 1000 | V/V |
| Gain Bandwidth Product ($C_L$ = 0.5 nF) | 14, 1 | 0.3 | – | – | MHz |
| $V_{out}$ Low ($R_L$ = 22 kΩ) | 1 | – | 0.45 | 0.65 | V |
| Phase Detector Tri–State Current | 14 | –15 | 0 | 15 | nA |
| Charge Pump Current of Phase Comparator ($T_{14}$ = 0) | 14 | 30 | 40 | 50 | µA |
| Charge Pump Current of Phase Comparator ($T_{14}$ = 1) | 14 | 90 | 125 | 150 | µA |
| $V_{CC2}$ Supply Voltage Range | 1 | 25 | 33 | 36 | V |

**PIN FUNCTION DESCRIPTION**

| Pin | Function | Description |
|---|---|---|
| 1 | $V_{TUN}/V_{CC2}$ | Output of the tuning voltage amplifier. Needs an external pull–up resistor to drive the varicaps |
| 2 | Gnd | Ground |
| 3, 4 | $HF_1$/ $HF_2$ | Symmetric HF inputs from local oscillator |
| 5 | $V_{CC1}$ | Supply voltage. Typical 5.0 V |
| 6, 7, 8 | $B_4$, $B_5$, $B_6$ | Band buffer outputs |
| 9 | CA | Chip address selection pin |
| 10 | SCL | Clock input of the $I^2C$ bus |
| 11 | SDA | Data input |
| 12 | DEC | Band decoder output for the mixer/oscillator circuit |
| 13 | Xtal | Crystal input |
| 14 | PHO | Input of tuning voltage amplifier |

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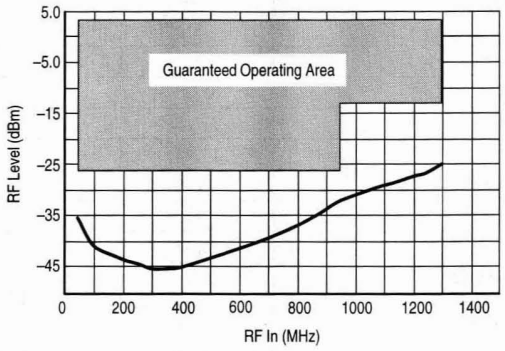
**Figure 1. Typical Prescaler Input Sensitivity**

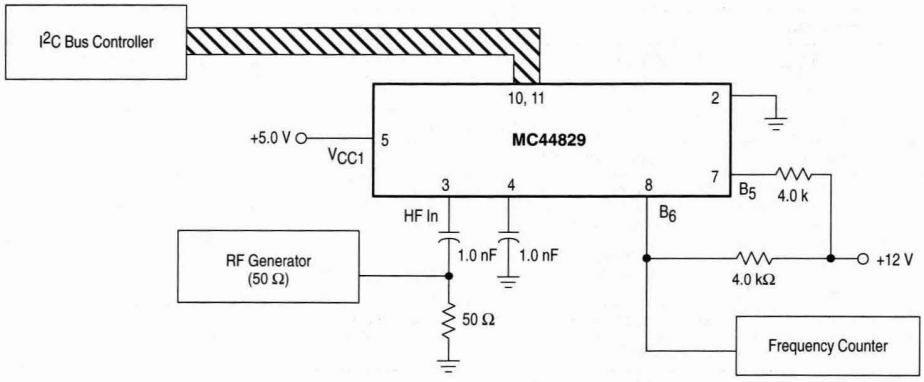



**NOTE:** $V_{CC}$ = 4.5 to 5.5 V, $T_A$ = – 20° to +80°C

**HF CHARACTERISTICS** (See Figure 1)

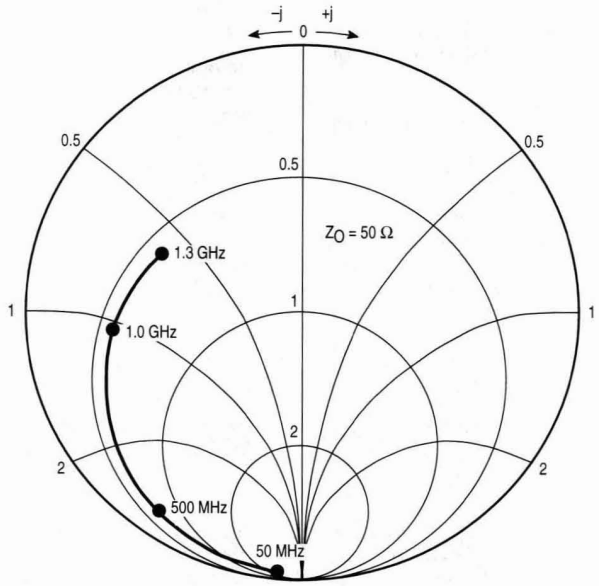
| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| DC Bias | 3, 4 | – | 1.6 | – | V |
| Input Voltage Range | | | | | mVrms |
| 50–950 MHz | 3, 4 | 10 | – | 315 | |
| 950–1300 MHz | 3, 4 | 50 | – | 315 | |

**Figure 2. RF Sensitivity Test Circuit**




Device is in test mode, $B_5$ and $B_6$ are "On", $B_4$ is "Off".
Sensitivity is the level of the HF generator of 50 Ω load.

**Figure 3. Typical HF Input Impedance**




**Data Format and Bus Receiver**

The circuit receives the information for tuning and control via the I²C bus. The incoming information, consisting of a chip address byte followed by two or four data bytes, is treated in the I²C bus receiver. The definition of the permissible bus protocol is shown below:

| | | | | | | |
|---|---|---|---|---|---|---|
| 1_STA | CA | CO | BA | STO | | |
| 2_STA | CA | FM | FL | STO | | |
| 3_STA | CA | CO | BA | FM | FL | STO |
| 4_STA | CA | FM | FL | CO | BA | STO |

STA = Start Condition
STO = Stop Condition
CA = Chip Address Byte
CO = Data Byte for Control Information
BA = Band Information
FM = Data Byte for Frequency Information (MSB's)
FL = Data Byte for Frequency Information (LSB's)

**Figure 4. Complete Data Transfer Process**

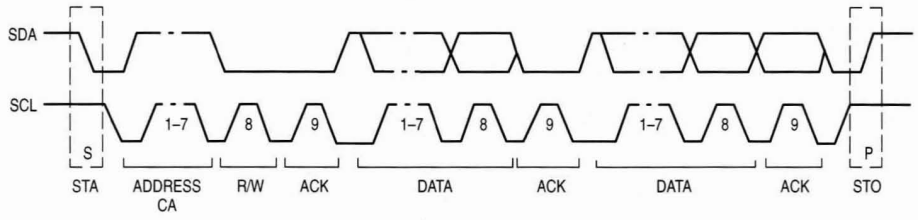


Figure 5 shows the five bytes of information that are needed for circuit operation: there is the chip address, two bytes of control and band information and two bytes of frequency information.

After the chip address, two or four data bytes may be received: if three data bytes are received the third data byte is ignored.

If five or more data bytes are received the fifth and following data bytes are ignored and the last acknowledge pulse is sent at the end of the fourth data byte.

The first and the third data bytes contain a function bit which allows the IC to distinguish between frequency information and control plus band information.

Frequency information is preceded by a Logic "0". If the function bit is Logic "1" the two following bytes contain control and band information. The first data byte, shifted after the chip address, may be byte CO or byte FM.

The two permissible bus protocols with five bytes are shown in Figure 5.

The Data and Clock inputs (Pins 10 and 11) are high impedance when the supply voltage $V_{CC1}$ is between 0 and 5.5 V.

### Chip Address

The chip address is programmable by Pin 9 (CA – Address Select).

| CA – Pin 9 | Address (HEX.) |
|---|---|
| –0.04 $V_{CC1}$ to 0.1 $V_{CC1}$ | $C_0$ |
| Open or 0.2 $V_{CC1}$ to 0.3 $V_{CC1}$ | $C_2$ |
| 0.42 $V_{CC1}$ to 0.75 $V_{CC1}$ | $C_4$ |
| 0.9 $V_{CC1}$ to 1.2 $V_{CC1}$ | $C_6$ |

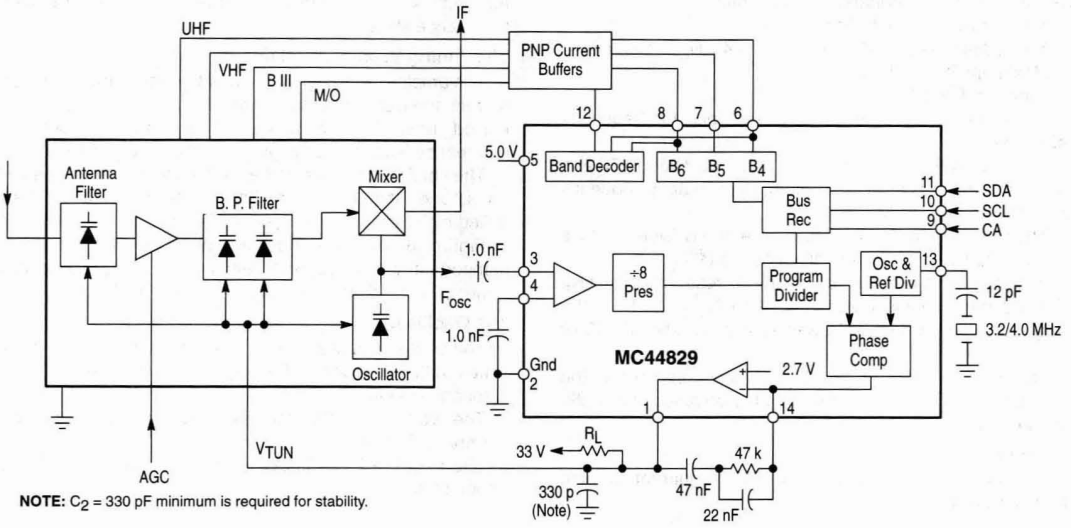
**Figure 5. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| | | | | | | | | | |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | X | $B_6$ | $B_5$ | $B_4$ | X | X | X | X | ACK |
| | | | | | | | | | |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA_Chip Address | 1 | 1 | 0 | 0 | 0 | 0/1 | 0/1 | 0 | ACK |
| | | | | | | | | | |
| FM_Frequency Information | ⓪ | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |
| | | | | | | | | | |
| CO_Information | ① | $T_{14}$ | $T_{13}$ | $T_{12}$ | $T_{11}$ | $T_{10}$ | $T_9$ | $T_8$ | ACK |
| BA_Band Information | X | $B_6$ | $B_5$ | $B_4$ | X | X | X | X | ACK |

9

**Figure 6. Typical Tuner Application**




**NOTE:** $C_2$ = 330 pF minimum is required for stability.

### Bits $B_4$, $B_5$, $B_6$: Control the Band Buffers

| | |
|---|---|
| $B_4$, $B_5$, $B_6$ = 0 | Buffer "Off" |
| = 1 | Buffer "On" |

### Bit $T_8$: Controls the Output of the Operational Amplifier

| | |
|---|---|
| $T_8$ = 0 | Normal Operation<br>Operational Amplifier Active |
| = 1 | Output State of Operational Amplifier Switched "Off",<br>Output Pulls High Through the External Pull–Up Resistor $R_L$ |

### Bits $T_9$, $T_{12}$: Control the Phase Comparator

| $T_9$ | $T_{12}$ | Function |
|---|---|---|
| 1 | 0 | Normal Operation |
| 1 | 1 | High Impedance (Tri–State) |
| 0 | 0 | Upper Source "On" Only |
| 0 | 1 | Lower Source "On" Only |

### Bits $T_{10}$, $T_{11}$: Control the Reference Divider

| $T_{10}$ | $T_{11}$ | Division Ratio |
|---|---|---|
| 0 | 0 | 512 |
| 0 | 1 | 1024 |
| 1 | 0 | 1024 |
| 1 | 1 | 512 |

### Bit $T_{13}$: Switches the Internal Signals $F_{ref}$ and $F_{BY2}$ to the Band Buffer Outputs (Test)

| | |
|---|---|
| $T_{13}$ = 0 | Normal Operation |
| = 1 | Test Mode<br>$F_{ref}$ Output at $B_5$ (Pin 7)<br>$F_{BY2}$ Output at $B_6$ (Pin 8) |

Bits $B_5$ and $B_6$ have to be "On", $B_5$ = $B_6$ = 1 in the test mode.
$F_{ref}$ is the reference frequency.
$F_{BY2}$ is the output frequency of the programmable divider, divided by two.

### Bit $T_{14}$: Controls the Charge Pump Current of the Phase Comparator

| | |
|---|---|
| $T_{14}$ = 0 | Pump Current 40 µA Typical |
| = 1 | Normal Operation. Pump Current 125 µA Typical |

### Mixer/Oscillator Band Decoder

The band decoder provides the band switching signal for the mixer/oscillator circuit. The buffer bits $B_4$ and $B_6$ control the decoder output. $B_5$ is not decoded. The decoder is controlled by the buffer bits as per the table below.

| $B_6$ | $B_5$ | $B_4$ | Decoder Output DEC |
|---|---|---|---|
| 0 | X | 0 | Undefined |
| 0 | X | 1 | 3.4 V to $V_{CC1}$ ($V_{CC1}$ = 4.5 to 5.5 V) |
| 1 | X | 0 | 0 to 0.8 V |
| 1 | X | 1 | 1.8 to 2.1 V |

### BA_Band Information

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| X | $B_6$ | $B_5$ | $B_4$ | X | X | X | X | ACK |

The band buffers are open collector buffers and are active "low" at Bn = 1. They are designed for 5.0 mA with a typical "on" voltage of 160 mV. These buffers are designed to withstand relative high output voltage in the "off" state.

$B_5$ and $B_6$ buffers may also be used to output internal IC signals (reference frequency and programmable divider output frequency divided by 2) for test purposes.

The bit $B_5$ and/or $B_6$ have to be one if the buffers are used for these additional functions.

### The Programmable Divider

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider, this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8132 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

Minimum Ratio 256

Where $N_0$ ... $N_{14}$ are the different bits for frequency information.

The counter may be used for any ratio between 256 and 32767 and reloads correctly as long as its output frequency does not exceed 1.0 MHz.

The data transfer between latches A and B (signal TDI) is also initiated by any start condition on the $I^2C$ bus.

At power "on" the whole bus receiver is reset and the bit $N_8$ of the programmable divider is set to $N_8 = 1$. Thus the programmable divider starts with a division ratio of 256 or higher.

The first $I^2C$ message must be sent only when the POWER ON RESET is completed. Division ratios of $N < 256$ are not allowed.

**The Prescaler**

The prescaler has a preamplifier which guarantees high input sensitivity.

**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**The Tuning Voltage Amplifier**

The amplifier is designed for very low noise, low input bias current and high power supply rejection. The positive input is biased internally. The tuning voltage amplifier needs an external pull–up resistor to generate the tuning voltage.

The amplifier can be switched "off" through bit $T_8$. When bit $T_8$ is "One", the amplifier is "Off". The tuning voltage is then pulled high by the external pull–up resistor.

Figure 6 shows a possible filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

**The Oscillator**

The oscillator uses a 3.2 or 4.0 MHz crystal tied to ground in series with a capacitor. The crystal operates in its series resonance mode.

The voltage at Pin 13, has low amplitude and low harmonic distortion.

The negative impedance of the crystal input (Pin 13) is about 3.0 kΩ.

MOTOROLA

*Advance Information*

# PLL Tuning Circuit with 1.3 GHz Prescaler and D/A Converters for Automatic Tuner Alignment

**MC44864**

**PLL TUNING CIRCUIT WITH 1.3 GHz PRESCALER AND D/A CONVERTERS**

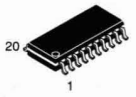
**SEMICONDUCTOR TECHNICAL DATA**

The MC44864 is a tuning circuit for TV applications. This device contains a PLL section and a DAC section and is MCU controlled through an $I^2C$ Bus.

The PLL section contains all the functions required to control the VCO of a TV tuner. The IC generates the tuning voltage and the additional control signals, such as band switching voltages.

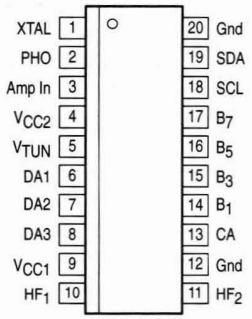
The D/A section generates three additional varactor voltages to feed all of the varactors of the tuner with individually optimized control voltages (automatic tuner adjustment). The MC44864 is manufactured on a single silicon chip using Motorola's high density bipolar process, MOSIAC™ (Motorola Oxide Self–Aligned Implanted Circuits).

- Complete Single Chip System for MPU Control
- Selectable ÷8 Prescaler Accepts Frequencies up to 1.3 GHz
- 15 Bit Programmable Divider Accepts Input Frequencies up to 165 MHz
- Programmable Reference Divider
- 3–State Phase/Frequency Comparator
- Operational Amplifier for Direct Varactor Control with Low Saturation Voltage
- Four Output Buffers (15 mA)
- Output Options for 62.5 kHz, Reference Frequency and the Programmable Divider
- The HF Input is Symmetrical
- Three 6 Bit DACs for Automatic Tuner Adjustment Allowing Use of Non–Matched Varactors
- Better Tuner Performances Through Optimum Filter Response
- $I^2C$ Bus Controlled
- Four Chip Addresses for the PLL Section
- Four Chip Addresses for the D/A Section
- ESD Protected to MIL–STD–883C, Method 3015.7 (2,000 V, 1.5 kΩ, 150 pF)




**M SUFFIX**
PLASTIC PACKAGE
CASE 967
(EIAJ–20)

**PIN CONNECTIONS**




(Top View)

**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted.)

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Power Supply Voltage ($V_{CC1}$) | 9 | 6.0 | V |
| Band Buffer "Off" Voltage | 14 – 17 | 15 | V |
| Band Buffer "On" Current | 14 – 17 | 20 | mA |
| Operational Amplifier Power Supply Voltage ($V_{CC2}$) | 4 | 36 | V |
| Operational Amplifier Short Circuit Duration (0 to $V_{CC2}$) | 5 – 8 | Continuous | S |
| Storage Temperature | – | –65 to +150 | °C |
| Operating Temperature Range | – | 0 to +70 | °C |

**NOTE:** ESD data available upon request.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC44864M | $T_A$ = 0° to +70°C | EIAJ–20 |

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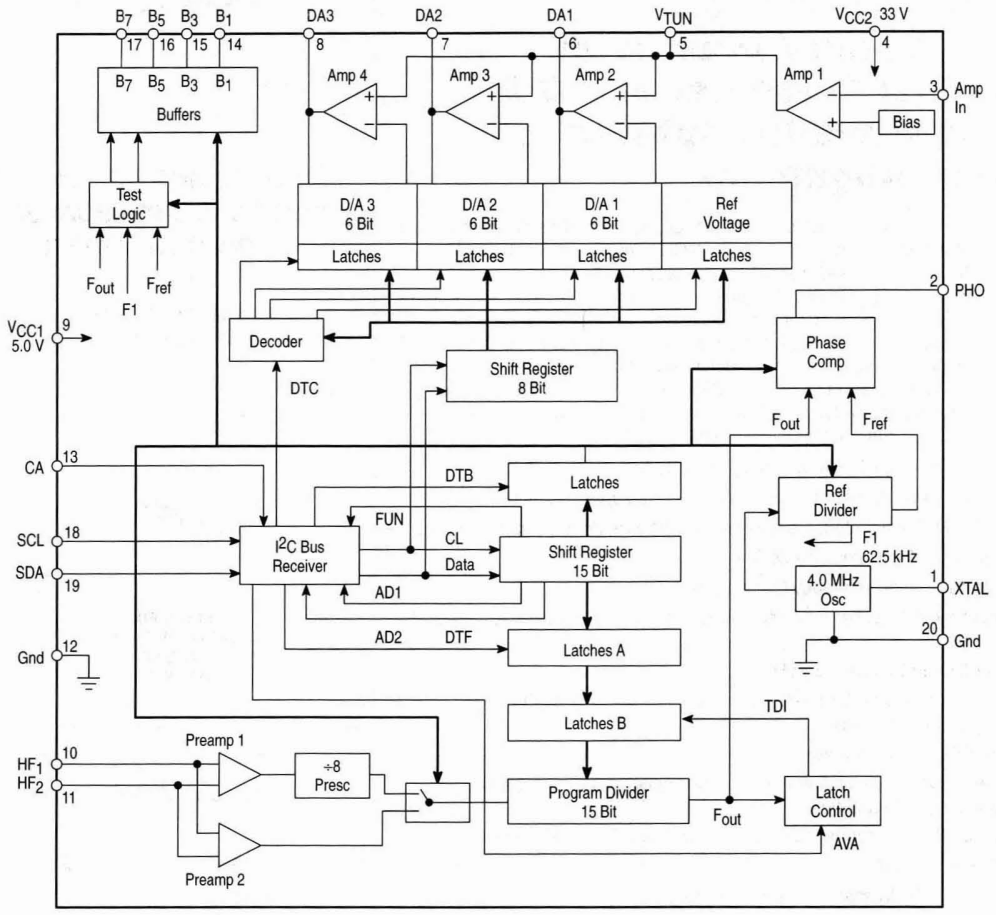
**Representative Block Diagram**




This device contains 3,551 active transistors.

**ELECTRICAL CHARACTERISTICS** ($V_{CC1}$ = 5.0 V, $V_{CC2}$ = 32 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $V_{CC1}$ Supply Voltage Range | 9 | 4.5 | 5.0 | 5.5 | V |
| $V_{CC1}$ Supply Current ($V_{CC1}$ = 5.0 V)(1)(2) | 9 | – | 50 | 70 | mA |
| $V_{CC2}$ Supply Voltage Range | 4 | 25 | 30 | 35 | V |
| $V_{CC2}$ Supply Current (Output Open) | 4 | – | 1.3 | 2.5(4) | mA |
| Band Buffer Leakage Current when "Off" at 12 V | 14 – 17 | – | 0.01 | 1.0 | µA |
| Band Buffer Saturation Voltage when "On" at 15 mA | 14 – 17 | – | 1.8 | 2.0 | V |
| Data/Clock Current at 0 V | 18, 19 | –10 | – | 0 | µA |
| Clock Current at 5.0 V | 18 | 0 | – | 1.0 | µA |
| Data Current at 5.0 V Acknowledge "Off" | 19 | 0 | – | 1.0 | µA |
| Data Saturation Voltage at 15 mA Acknowledge "On" | 19 | – | 1.2 | – | V |
| Data/Clock Input Voltage Low | 18, 19 | – | – | 1.5 | V |
| Data/Clock Input Voltage High | 18, 19 | 3.0 | – | – | V |
| Clock Frequency Range | 18 | – | – | 100 | kHz |
| Phase Detector Current in High Impedance State | 2 | –15 | – | 15 | nA |
| Oscillator Frequency Range | 1, 2 | 3.5 | 4.0 | 4.1 | MHz |
| Phase Detector High–State Source Current (@ 1.5 V) | 2 | –2.5 | – | –0.5 | mA |
| Phase Detector Low–State Sink Current (@ 4.0 V) | 2 | 0.5 | – | 2.5 | mA |
| Operational Amplifier Internal Reference Voltage | – | 2.0 | 2.5 | 3.0 | V |
| Operational Amplifier Input Current | 3 | –15 | – | 15 | nA |
| DC Open Loop Gain | – | 2000 | – | – | V/V |
| Gain Bandwidth Product | – | – | 0.2 | – | MHz |
| Phase Margin | – | – | 50 | – | Deg. |
| $V_{out}$ Low, Sinking 50 µA | 6 – 8 | – | 0.2 | 0.5 | V |
| $V_{out}$ High, Sourcing 50 µA ($V_{CC2}$ – $V_{out}$ High) | 6 – 8 | – | – | 1.5 | V |
| Tuning Voltage (DC) | 5 – 8 | – | – | 30 | V |
| D/A Converters Step Size(3) | 6 – 8 | 0.5 | – | 1.5 | LSB |
| D/A Converters Temperature Drift | 6 – 8 | – | 1.0 | – | LSB |
| DAC Offset at $V_{TUN}$ = 2.5 V | – | –50 | – | 50 | mV |
| DAC Offset at $V_{TUN}$ = 25 V | – | –700 | – | 700 | mV |
| DAC Voltages (DC) | 6 – 8 | – | – | 33 | V |

**NOTES:** 1. When prescaler "Off", typical supply current is decreased by 10 mA.
2. Band Buffers "Off", 2.4 mA more when one buffer is on.
3. For definition of the LSB, see Figure 9 in the D/A section.
4. 2.5 mA as long as the analog outputs are not in saturation high, which means $V_{TUN}$, $V_{DAC}$ (Pins 5, 6, 7, 8) lower than $V_{CC2}$ – 1.5 V. When all outputs are in saturation high the maximum $V_{CC2}$ current is 5.0 mA.

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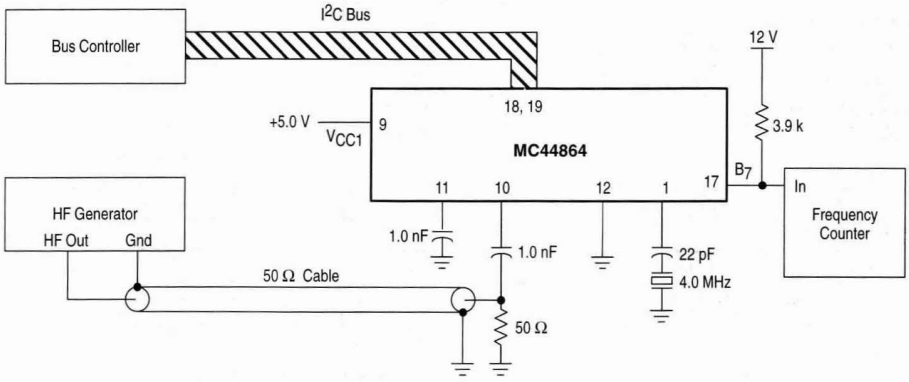
**HF CHARACTERISTICS** (See Figure 1)

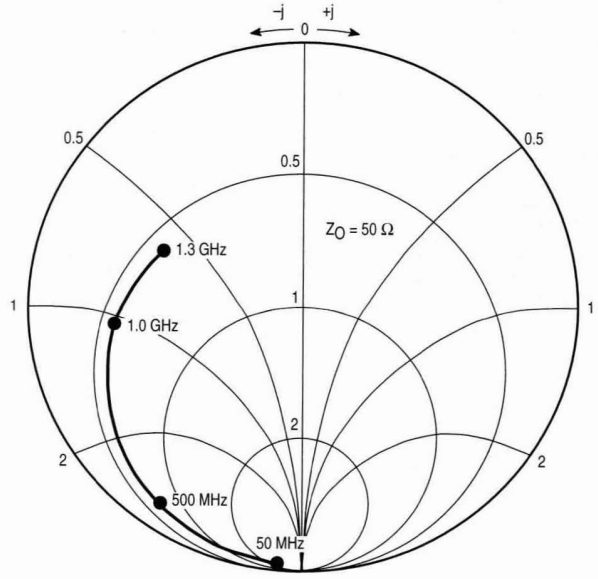
| Characteristic | Pin | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| DC Bias | 10, 11 | – | 1.55 | – | V |
| Input Voltage Range | | | | | mVrms |
| 10–150 MHz (Prescaler "Off") | 10, 11 | 20 | – | 315 | |
| 80–1000 MHz | 10, 11 | 20 | – | 315 | |
| 1000–1300 MHz | 10, 11 | 50 | – | 315 | |

**Figure 1. HF Sensitivity Test Circuit**




Device is in test mode: $B_7$ is "On", $R_2 = 1$ and $R_3 = 0$ (see Bus section).
Sensitivity is the level of the HF generator on 50 Ω load (without MC44864 load).

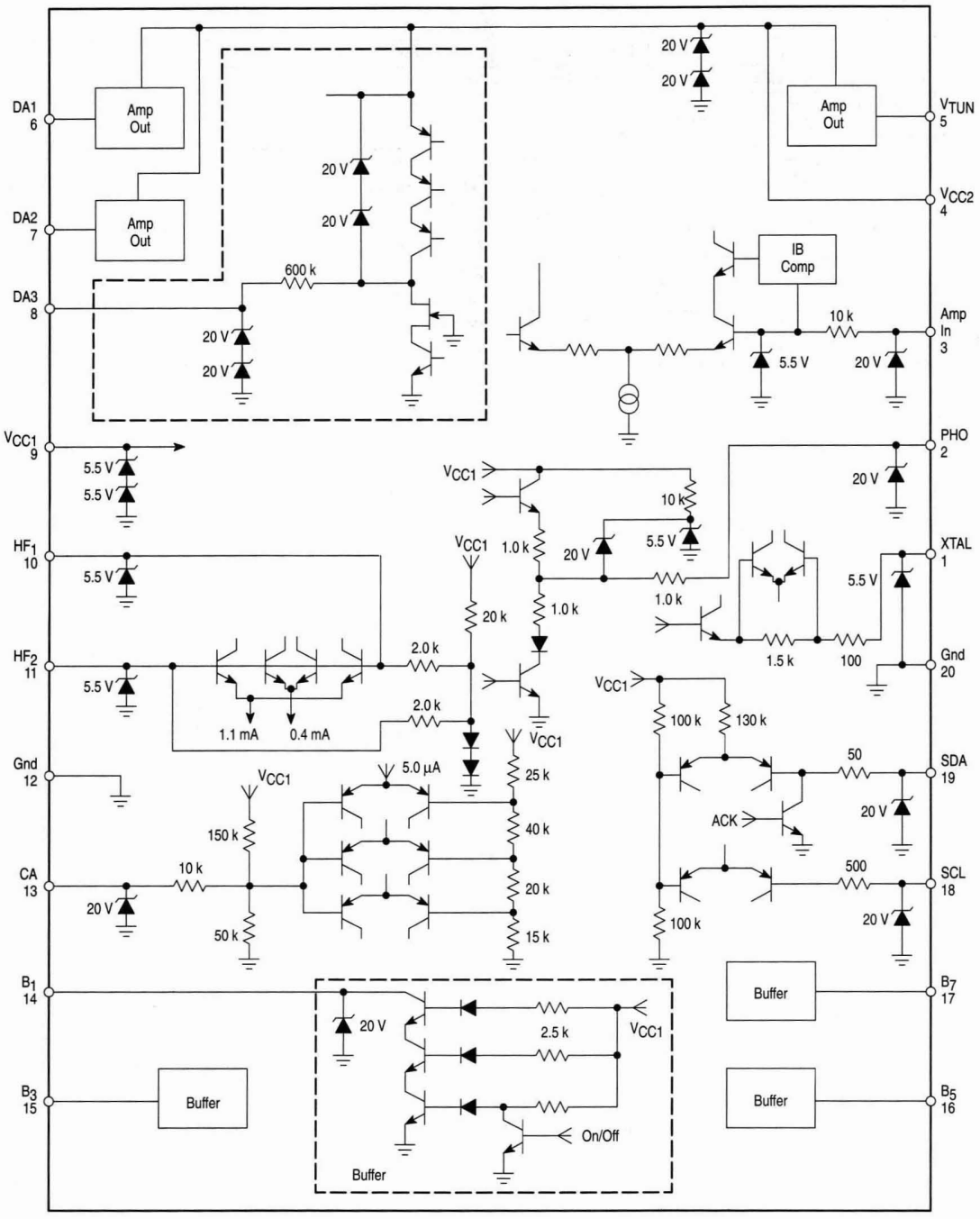
**Figure 2. Typical HF Input Impedance**



**PIN FUNCTION DESCRIPTION**

| Pin | Symbol | Description |
|---|---|---|
| 6, 7, 8 | DA1, DA2, DA3 | D/A output control voltages |
| 9 | $V_{CC1}$ | Positive supply of the circuit (except DACs) |
| 10, 11 | $HF_1$, $HF_2$ | HF input from local oscillator |
| 12, 20 | Gnd | Ground |
| 13 | CA | Chip Address |
| 14, 15, 16, 17 | $B_1$, $B_3$, $B_5$, $B_7$ | Band buffer output can drive 15 mA |
| 18 | SCL | Clock input (supplied by the microprocessor via Bus) |
| 19 | SDA | Data input (bus) |
| 1 | XTAL | Crystal oscillator (typically 4.0 MHz) |
| 2 | PHO | Phase comparator output |
| 3 | Amp In | Negative operational amplifier input |
| 4 | $V_{CC2}$ | Operational amplifier positive supply |
| 5 | $V_{TUN}$ | Operational amplifier output which provides the tuning voltage |

**Figure 3. Pin Circuit Schematic**



## FUNCTIONAL DESCRIPTION

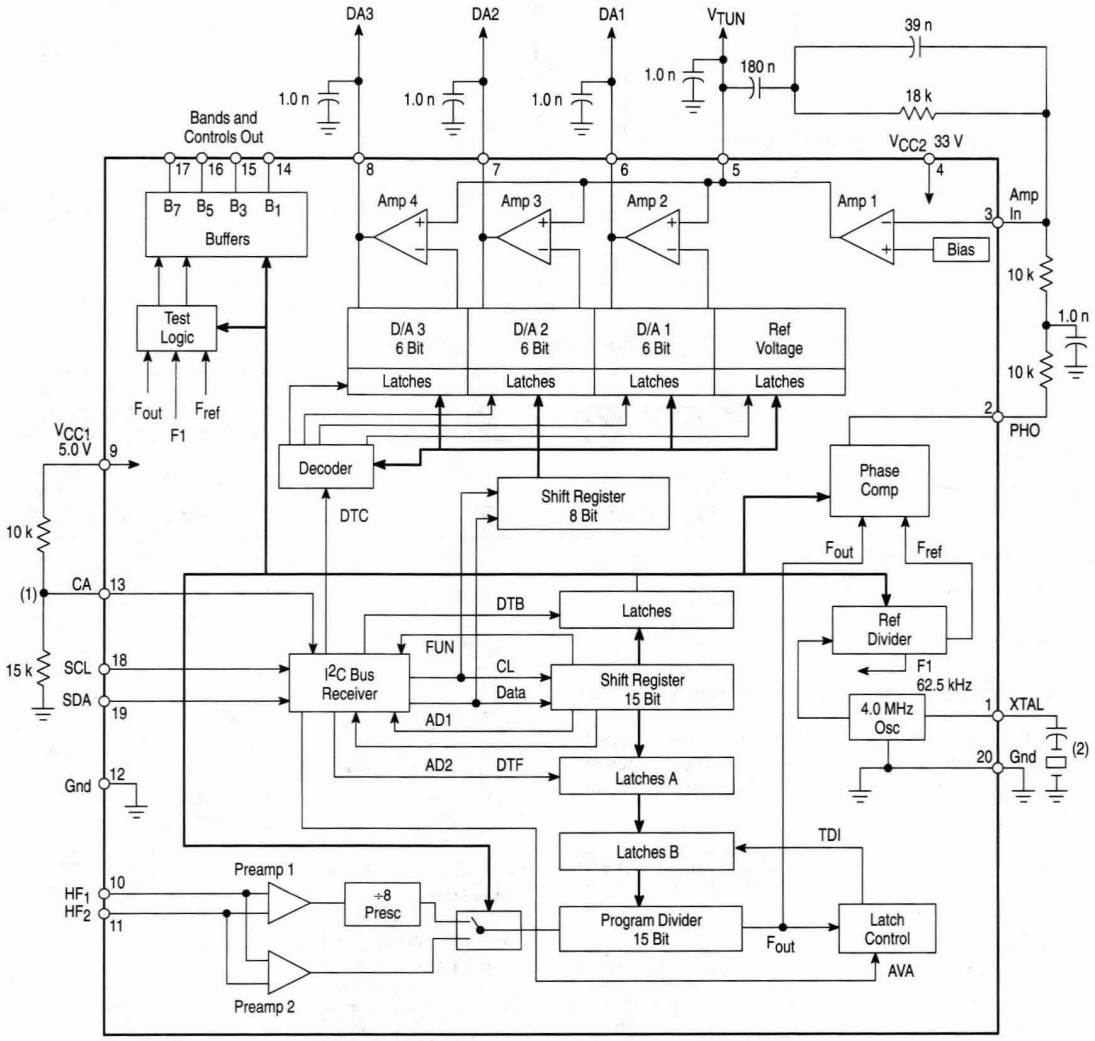
A representative block diagram and a typical system application are shown in Figures 4 and 5. A discussion of the features and function of the internal blocks is given below.

### Automatic Tuner Alignment

The circuit generates the tuning voltage through the PLL. The output voltages of the D/A converters are equal to the tuning voltage plus a positive or negative offset of up to 31 steps. During the automatic alignment one first lets the PLL lock to the appropriate frequency and then searches for the optimum value of the other varactor voltages. The digital word for each voltage value is stored in a nonvolatile memory (NVM). Hence, for each frequency point to be adjusted, three times 6 bits of information have to be stored (plus 2 bits for the DAC range).

The information stored in the NVM reflects the characteristic of the individual tuner. For this reason, the NVM is preferably situated inside the tuner and is also controlled by the I²C Bus.

**Figure 4. Block Diagram**




**NOTES:** 1. Pin 13: Short to $V_{CC}$ for addresses CC, CE
Resistors ±10% for addresses C8, CA (values 10 k and 15 k) for test only
Open or 1.0 nF to Gnd for addresses C4, C6
Short to Gnd for addresses C0, C2

2. The crystal may be connected to Pin 20 with no connection to external Gnd.

**Figure 5. TV Tuner for Automatic Alignment**

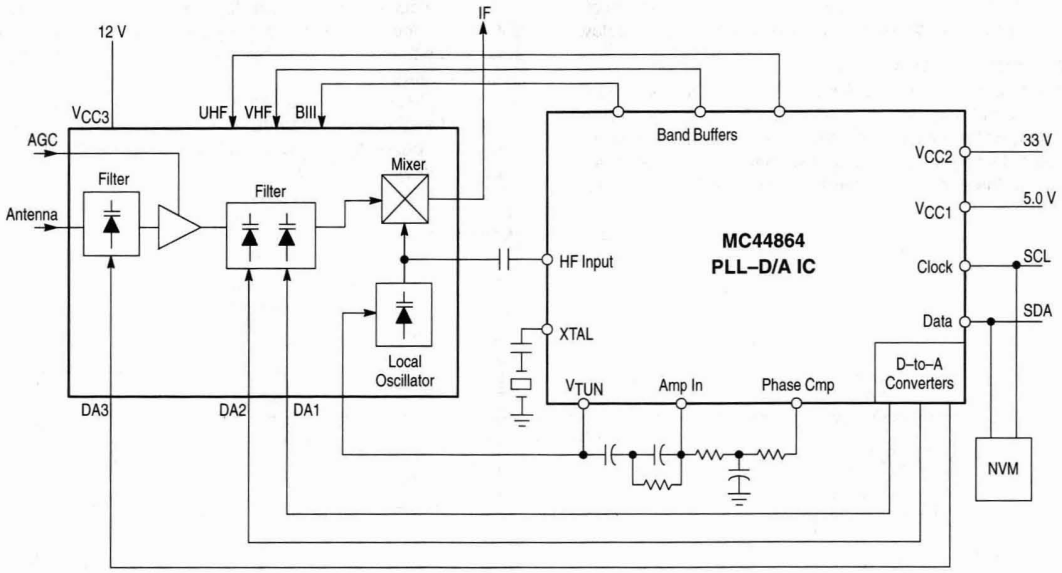



**Figure 6. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA1_PLL Chip Address | 1 | 1 | 0 | 0 | $A_3$ | $A_2$ | $A_1$ | $A_0 = 0$ | ACK |
| | | | | | | | | | |
| CO_Control Information | 1 | $R_6$ | T | P | $R_3$ | $R_2$ | $R_1$ | $R_0$ | ACK |
| BA_Band Information | $B_7$ | X | $B_5$ | X | $B_3$ | X | $B_1$ | X | ACK |
| | | | | | | | | | |
| FM_Frequency Information (with MSB) | 0 | $N_{14}$ | $N_{13}$ | $N_{12}$ | $N_{11}$ | $N_{10}$ | $N_9$ | $N_8$ | ACK |
| FL_Frequency Information (with LSB) | $N_7$ | $N_6$ | $N_5$ | $N_4$ | $N_3$ | $N_2$ | $N_1$ | $N_0$ | ACK |

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### Chip Addresses

The chip address is programmable by Pin CA.

The PLL addresses C0, C2, C4, C6 are officially allocated to PLL–IC's.

The addresses C8, CA, CC, CE are not officially allocated. Care has to be taken in the application that no conflict occurs with other devices on the same $I^2C$ Bus when using the addresses C8 to CE.

| CA Pin (13) | $A_3$ | $A_2$ | $A_1$ | $A_0$ | Address | Function |
|---|---|---|---|---|---|---|
| –0.04 $V_{CC1}$ to 0.1 $V_{CC1}$ | 0 | 0 | 0 | 0 | C0 | 1st PLL |
| | 0 | 0 | 1 | 0 | C2 | 1st DAC |
| Open or 0.2 $V_{CC1}$to0.3$V_{CC1}$ | 0 | 1 | 0 | 0 | C4 | 2nd PLL |
| | 0 | 1 | 1 | 0 | C6 | 2nd DAC |
| 0.42 $V_{CC1}$ to 0.75 $V_{CC1}$ | 1 | 0 | 0 | 0 | C8 | 3rd PLL |
| | 1 | 0 | 1 | 0 | CA | 3rd DAC |
| 0.9 $V_{CC1}$ to 1.2 $V_{CC1}$ | 1 | 1 | 0 | 0 | CC | 4th PLL |
| | 1 | 1 | 1 | 0 | CE | 4th DAC |

## PLL SECTION

### Data Format and Bus Receiver

The circuit receives the information for tuning and control via $I^2C$ Bus. The incoming information is treated in the bus receiver. The definition of the permissible bus protocol is shown in the four examples below:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ex. 1 | STA | CA1 | CO | BA | STO | | |
| Ex. 2 | STA | CA1 | FM | FL | STO | | |
| Ex. 3 | STA | CA1 | CO | BA | FM | FL | STO |
| Ex. 4 | STA | CA1 | FM | FL | CO | BA | STO |

STA = Start Condition
STO = Stop Condition
CA1 = Chip Address Byte of the PLL Section
CO = Data Byte for Control Information
BA = Band Information
FM = Data Byte for Frequency Information (MSB's)
FL = Data Byte for Frequency Information (LSB's)

Figure 6 shows the five bytes of information that are needed for circuit operation: there is a chip address, two bytes of control and band information and two bytes of frequency information.

After the chip address, two or four data bytes may be received: if three data bytes are received, the third data byte is ignored. If five or more data bytes are received, the fifth and following data bytes are ignored and the last acknowledge pulse is sent at the end of the fourth data byte.

The first and the third data bytes contain a function bit F. If the function bit F= 0, frequency information is acknowledged and if F = 1, control/band information is acknowledged.

If the address is correct (signal AD1) the information is loaded into latches.

A function bit in the first and third data byte is used to pass this data either into the latches of the programmable divider (signal DTF) or into the latches for band and control information (signal DTB). The data transfer to the latches (signals DTF and DTB) is initiated after the 2nd and 4th data bytes.

A second string of latches is used for the data transfer into the programmable divider to inhibit the transfer during the preset operation (signal TDI, signal AVA is an internal "address valid" command).

The switching levels of clock and data (Pins 18 and 19) are 0.5 x $V_{CC1}$.

The control and band information bits have the following functions.

**Bits $R_0$, $R_1$: Controls Reference Divider Division Ratio**

| $R_0$ | $R_1$ | Division Ratio |
|---|---|---|
| 0 | 0 | 2048 |
| 1 | 0 | 1024 |
| 0 | 1 | 512 |
| 1 | 1 | 256 |

**Bits $R_2$, $R_3$: Switches Internal Signals to the Buffer Outputs**

| $R_2$ | $R_3$ | Pin 16 | Pin 17 |
|---|---|---|---|
| 0 | 0 | – | – |
| 0 | 1 | 62.5 kHz | – |
| 1 | 0 | $F_{ref}$ | $F_{BY2}$ |
| 1 | 1 | – | – |

Bit $B_5$ has to be "one" when Pin 16 is used to output 62.5 kHz. Bits $B_5$ and $B_7$ have to be "one" to output $F_{ref}$ and $F_{BY2}$. $F_{BY2}$ is the programmable divider output frequency divided by two.

**Bits $R_2$, $R_6$, T: Controls the Phase Comparator Output Stage**

| $R_2$ | $R_6$ | T | Output State |
|---|---|---|---|
| 0 | 0 | 0 | Normal Operation |
| 0 | 0 | 1 | "Off" (High Impedance) |
| 0 | 1 | 0 | High |
| 0 | 1 | 1 | Low |
| 1 | 0 | 0 | Normal Operation |
| 1 | 0 | 1 | "Off" |
| 1 | 1 | 0 | Normal Operation |
| 1 | 1 | 1 | "Off" |

**The Band Buffers**

The band buffers are open collector transistors and are active "low" at Bn = 1. They are designed for 15 mA with typical on–voltage of 1.8 V. These buffers are designed to withstand relative high output voltage in the off–state (15 V).

$B_5$ and $B_7$ buffers (Pins 16 and 17) may also be used to output internal IC signals (reference frequency and programmable divider output frequency divided by 2) for test purposes.

Buffer $B_5$ may also be used to output a 62.5 kHz frequency from an intermediate stage of the reference divider. The bits $B_5$ and $B_7$ have to be "one" if the buffers are used for these additional functions.

**The Programmable Divider**

The programmable divider is a presettable down counter. When it has counted to zero it takes its required division ratio out of the latches B. Latches B are loaded from latches A by means of signal TDI which is synchronous to the programmable divider output signal.

Since latches A receive the data asynchronously with the programmable divider, this double latch scheme is needed to assure correct data transfer to the counter.

The division ratio definition is given by:

$N = 16384 \times N_{14} + 8192 \times N_{13} + \ldots + 4 \times N_2 + 2 \times N_1 + N_0$

Maximum Ratio 32767

Minimum Ratio 256

where $N_0$ ... $N_{14}$ are the different bits for frequency information.

The counter reloads correctly as long as its output frequency does not exceed 1.0 MHz.

Division ratios of < 256 are not allowed. At power–up the counter bit N8 is preset to "1". All other bits are undetermined. In this way, the counter always starts with a division ratio of 256 or higher.

The data transfer between latches A and B (signal TDI) is also initiated by any start condition on the bus.

At power–on the whole bus receiver is reset and the programmable divider is set to a counting ratio of N = 256 or higher.

**The Prescaler**

The prescaler has a preamplifier and may be bypassed (Bit P). The signal then passes through preamplifier 2.

The table on the following page shows the frequency ranges which may be synthesized with and without prescaler.

**The Phase Comparator**

The phase comparator is phase and frequency sensitive and has very low output leakage current in the high impedance state.

**The Operational Amplifier**

The operational amplifier for the tuning voltage is designed for low noise, low input bias current and high power supply rejection. The positive input is biased internally. The operational amplifier needs 30 V supply ($V_{CC2}$) as minimum voltage for a guaranteed maximum tuning voltage of 28.5 V.

Figure 4 shows the usual filter arrangement. The component values depend very much on the application (tuner characteristic, reference frequency, etc.).

As a starting point for optimization, the component values in Figure 4 may be used for 7.8125 kHz reference frequency in a multiband TV tuner.

**The Oscillator**

The oscillator uses a 4.0 MHz crystal tied to ground in series with a capacitor. The crystal operates in the series resonance mode.

The crystal is driven through a 1.6 kΩ resistor on chip.

The voltage at Pin 16 "crystal", has low amplitude and low harmonic distortion.

The negative resistance of the oscillator at Pin 1 (XTAL) is about 3.0 kΩ.

| Input Data | | Ref. Divider Div. Ratio | Ref. Freq. Hz(1) | With Int. Prescaler P = 0 | | Without Prescaler P = 1 | |
|---|---|---|---|---|---|---|---|
| $R_0$ | $R_1$ | | | Frequency Steps kHz | Max. Input Freq. MHz | Frequency Steps kHz | Max. Imput Freq. MHz |
| 0 | 0 | 2048 | 1953.125 | 15.625 | 512 | 1.953125 | 64 |
| 1 | 0 | 1024 | 3906.25 | 31.25 | 1024 | 3.90625 | 128 |
| 0 | 1 | 512 | 7812.5 | 62.5 | 1300(2) | 7.8125 | 165(3) |
| 1 | 1 | 256 | 15625.0 | 125.0 | 1300(2) | 15.625 | 165(3) |

**NOTES:** 1. With 4.0 MHz Crystal
2. Limit of Prescaler
3. Limit of Programmable Divider

For satellite tuner applications the circuit may be used with an external /4 prescaler and a reference divider ration of 1024 ($R_0$ = 1, $R_1$ = 0). In this way, frequencies up to 4.0 GHz can be synthesized with 125 kHz resolution (4.0 MHz crystal).

The same result can be achieved with an external /32 prescaler when the internal prescaler is bypassed (P = 1).

### The Reference Divider

The reference divider of the MC44864 is programmable (Bits $R_0$ and $R_1$) for ratios of 2048, 1024, 512 and 256. This feature makes the circuit versatile.

### Bit P: Controls the Prescaler

| P | Prescaler Function |
|---|---|
| 0 | Prescaler Active |
| 1 | Prescaler Bypassed<br>Prescaler Power Supply "Off" |

### Bits $B_1$, $B_3$, $B_5$, $B_7$: Controls the Band Buffers

| | |
|---|---|
| $B_1$, $B_3$, $B_5$, $B_7$ = 0 | Buffer "Off" |
| = 1 | Buffer "On" |

## D/A SECTION

### Basic Function

The D/A section has four separate chip addresses from the PLL section. Three D–to–A converters that have a resolution of 6 bits (5 bits plus sign) are on chip. The analog output voltages are dc. The converters are buffered to the analog outputs DA1, DA2 and DA3 by operational amplifiers with an output voltage range that is equal to the tuning voltage range (about 0 to 30 V). The operational amplifiers are arranged such that a positive or negative offset can be generated from the tuning voltage.

### Data Format and Bus Protocols

The D–to–A information consists of the D/A chip address (CA2) and four data bytes. The first two bits of the data bytes are used as the function address. Thus the bytes $C_1$, $C_2$ and $C_3$ contain the address for the individual converter and the 6 bits to be converted. Bit $D_5$ is the sign (log "1" for positive offset, log "0" for negative offset) and the bits $D_0$ to $D_4$ determine the number of steps to be made as an offset from the tuning voltage. The bits $S_0$ and $S_1$ in the data byte RA define the step size ($V_{step}$) and the range of the converters (see Figures 8 and 9). The range is the same for all converters.

After the chip address (CA2) is acknowledged, up to four data bytes may be received by the IC. If more than four bytes are received, the fifth and following bytes are ignored and the last acknowledge pulse is sent after the fourth data byte. The data transfer to the converters (signal DTC) is initiated each time a complete data byte is received.

The following shows some examples of the permissible bus protocols of the D–to–A section. The data bytes may be sent to the IC in random order with up to four in one sequence. The same converter may be loaded up to four times as shown in example 6. Below are 6 examples of permissible bus protocols.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ex. 1 | STA | CA2 | C1 | STO | | | |
| Ex. 2 | STA | CA2 | C1 | C2 | STO | | |
| Ex. 3 | STA | CA2 | C1 | C2 | C3 | STO | |
| Ex. 4 | STA | CA2 | C1 | C2 | C3 | RA | STO |
| Ex. 5 | STA | CA2 | RA | C1 | C2 | C3 | STO |
| Ex. 6 | STA | CA2 | C1 | C1 | C1 | C1 | STO |

STA = Start Condition
STO = Stop Condition
CA2 = Chip Address Byte for D/A Section
C1, C2, C3 = Data Bytes for D/A Converters
RA = Data Byte for Range

**Figure 7. Definition of Bytes**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CA2_D/A Chip Address | 1 | 1 | 0 | 0 | $A_2$ | $A_1$ | $A_0$ = 0 | | ACK |
| C1_Converter 1 | 0 | 0 | $D_5$ | $D_4$ | $D_3$ | $D_2$ | $D_1$ | $D_0$ | ACK |
| C2_Converter 2 | 0 | 1 | $D_5$ | $D_4$ | $D_3$ | $D_2$ | $D_1$ | $D_0$ | ACK |
| C3_Converter 3 | 1 | 0 | $D_5$ | $D_4$ | $D_3$ | $D_2$ | $D_1$ | $D_0$ | ACK |
| RA_Range Selection | 1 | 1 | X | X | X | X | $S_1$ | $S_0$ | ACK |

**Figure 8. Output Voltage (D/A Converters)**

| $V_{DA} = V_{TUN} \pm V_{step} (D_0 + 2\ D_1 + 4\ D_2 + 8\ D_3 + 16\ D_4)$ |
|---|
| $D_5 = 1$ positive sign; $D_5 = 0$ negative sign |
| $V_{TUN}$: Tuning Voltage set by PLL<br>$V_{step}$: Voltage Step (LSB) of the D/A Converters |

**Figure 9. Range Selection of the D/A Converters**

| Input Data | | Typ. Step Size $V_{step}$ | Guaranteed Range 31 Steps |
|---|---|---|---|
| $S_0$ | $S_1$ | | |
| 0 | 0 | 225 mV | 6.25 V |
| 1 | 0 | 125 mV | 3.40 V |
| 0 | 1 | 70 mV | 1.90 V |
| 1 | 1 | 40 mV | 1.05 V |

### The D/A Converters

The D/A converters convert 5 bit into analog current of which the polarity is switched by the sixth bit. The reference voltage of the converters is programmed by two bits ($S_0$, $S_1$ of the RA–byte) to determine the scaling factor. The analog currents are then converted into voltages and added to their respective operational amplifier nominal bias. The resulting voltages at Pins 6, 7 and 8 are the tuning voltages ($V_{TUN}$, see Figure 4) at Pin 5 plus any offset provided by information in the D/A converters.

If the data bits $D_0$ to $D_4$ are all "0", the three D/A output voltages on Pins 6, 7 and 8 are equal to the tuning voltage (Pin 5) within the DAC offset voltages.

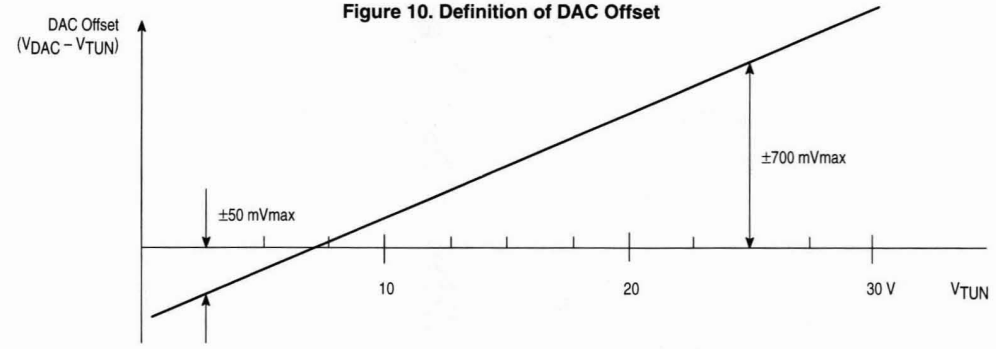
The four amplifiers have the same output characteristics with the maximum output voltage being 1.5 V lower than $V_{CC2}$ in the worst case. The four analog outputs are short–circuit protected. At power–up, the D/A outputs are undetermined.

The D/A converters are guaranteed to be monotonic with a voltage step variation of ±0.5 LSB.

The D/A converters work correctly as long as the PLL loop is active. $V_{TUN}$ is then between 0.3 V and $V_{CC2} - 1.5$ V. If the loop saturates, the DACs do not work.

The DAC–OFFSET is defined as the difference between the DAC output voltage (with bits $D_0$ to $D_4 = 0$) and the tuning voltage (PLL active). The DAC operation is guaranteed from 0.3 V to $V_{CC2} - 1.5$ V. On typical samples, the DACs will operate down to 0.2 V.

**Figure 10. Definition of DAC Offset**




9

# Automotive Electronic Circuits

## In Brief . . .

Motorola Analog has established itself as a global leader in custom integrated circuits for the automotive market. With multiple design centers located on four continents, global process and assembly sites, and strategically located supply centers, Motorola serves the global automotive market needs. These products are key elements in the rapidly growing engine control, body, navigation, entertainment, and communication electronics portions of modern automobiles. Though Motorola is most active in supplying automotive custom designs, many of yesterday's proprietary custom devices have become standard products of today, available to the broad base manufacturers who support this industry. Today, based on new technologies, Motorola offers a wide array of standard products ranging from rugged high current "smart" fuel injector drivers which control and protect the fuel management system through the rigors of the underhood environment, to the latest SMARTMOS™ switches and series transient protectors. Several devices are targeted to support microprocessor housekeeping and data line protection. A wide range of packaging is available including die, flip–chip, and SOICs for high density layouts, to low thermal resistance multi–pin, single–in–line types for high power control ICs.


| | Page |
|---|---|
| Voltage Regulators | 10–2 |
| Electronic Ignition | 10–2 |
| Special Functions | 10–3 |
| Package Overview | 10–13 |
| Device Listing | 10–14 |

# Automotive Electronic Circuits

## Table 1. Voltage Regulators

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| Low Dropout Voltage Regulator | Positive fixed and adjustable output voltage regulators which maintain regulation with very low input to output voltage differential. | Z/29, T/221A, T/314D, TH/314A, TV/314B, DT/369A, DT–1/369, D2T/936, D2T/936A, D/751 | LM2931, C |
| Low Dropout Dual Regulator | Positive low voltage differential regulator which features dual 5.0 V outputs, with currents in excess of 750 mA (switched) and 10 mA standby, and quiescent current less than 3.0 mA. | T/314D, TH/314A, TV/314B, D2T/936A | LM2935 |
| Automotive Voltage Regulator | Provides load response control, duty cycle limiting, under/overvoltage and phase detection, high side MOSFET field control, voltage regulation in 12 V alternator systems. | DW/751D | MC33092 |
| Low Dropout Voltage Regulator | Positive 5.0 V, 500 mA regulator having on–chip power–up–reset circuit with programmable delay, current limit, and thermal shutdown. | T/314D, TV/314B | MC33267 |
| Low Dropout Voltage Regulator | Positive 3.3 V, 5.0 V, 12 V, 800 mA regulator. | D/751, DT/369A | MC33269 |

## Table 2. Electronic Ignition

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| Electronic Ignition Circuit | Used in high energy variable dwell electronic ignition systems with variable reluctance sensors. Dwell and spark energy are externally adjustable. "Bumped" die for inverted mounting to substrate. | P/626, D/751, Flip–Chip | MC3334, MCCF3334 |
| Electronic Ignition Circuit | Used in high energy electronic ignition systems requiring differential Hall Sensor control. "Bumped" die for inverted mounting to substrate. | DW/751G, Flip–Chip | MC33093, MCCF33093 |
| Electronic Ignition Circuit | Used in high energy electronic ignition systems requiring single Hall Sensor control. "Bumped" die for inverted mounting to substrate. | DW/751G, Flip–Chip | MC33094, MCCF33094 |
| Electronic Ignition Circuit | Used in high energy electronic ignition systems requiring single Hall Sensor control. Dwell feedback for coil variation. "Bumped" die for inverted mounting to substrate. | DW/751G, Flip–Chip | MC79076, MCCF79076 |

## Table 3. Special Functions

| Function | Features | Suffix/ Package | Device |
|---|---|---|---|
| Low Side Protected Switch | Single automotive low side switch having CMOS compatible input, 1.0 A maximum rating, with overcurrent, overvoltage and thermal protection. | T/221A, T–1/314D, DW/751G | MC3392 |
| Low Current High–Side Switch | Drives loads from positive side of power supply and protects against high–voltage transients. | T/314D, DW/751G | MC3399 |
| High–Side TMOS Driver | Designed to drive and protect N–channel power MOSFETs used in high side switching applications. Has internal charge pump, externally programmed timer and fault reporting. | P/626, D/751 | MC33091A |
| MI–Bus Interface Stepper Motor Controller | High noise immunity serial communication using MI–Bus protocol to control relay drivers and motors in harsh environments. Four phase signals drive two phase motors in either half or full–step modes. | DW/751G | MC33192 |
| Quad Fuel Injector Driver | Four low side switches with parallel CMOS compatible input control, ≤7.0 mA quiescent current, 0.25 Ω $r_{DS(on)}$ at 25°C independent outputs with 3.0 A current limiting and internal 65 V clamps. | T/821D, TV/821C | MC33293A |
| Octal Serial Output Switch | Eight low side switches having 8–bit serial CMOS compatible input control, serial fault reporting, ≤4.0 mA quiescent current, independent 0.45 Ω $r_{DS(on)}$ at 25°C outputs with 3.0 A minimum current limiting and internal 55 V clamps. | P/738, DW/751E | MC33298 |
| Integral Alternator Regulator | Control device used in conjunction with a Darlington device to monitor and control the field current in alternator charging systems. "Bumped" die for inverted mounting to substrate. | D/751A, Flip–Chip | MC33095 MCCF33095 |
| Peripheral Clamping Array | Protects up to six MPU I/O lines against voltage transients. | */626, D/751 | TCF6000 |
| Automotive Direction Indicator | Detects defective lamps and protects against overvoltage in automotive turn–signal applications. Replaces UAA1041B in most applications. | D/751, P/626 | MC33193 |
| Automotive Wash Wiper Timer | Standard wiper timer control device that drives a wiper motor relay and can perform the intermittent, afterwash and continuous wiper timer functions. | D/751, P/626 | MC33197A |
| Automotive ISO 9141 Serial Link Driver | Interface between the two–wire asynchronous serial communication interface (SCI) of a microcontroller and a special one–wire care diagnosis system (DIA). | D/751A | MC33199 |

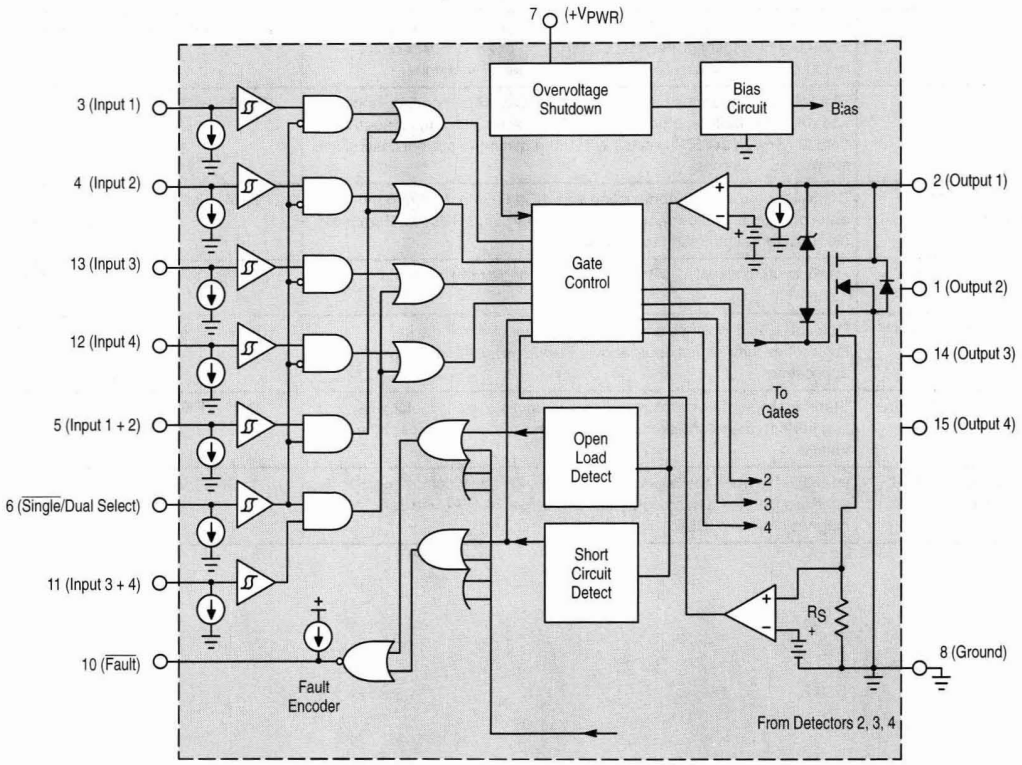
* No Suffix

# Quad Fuel Injector Driver

**MC33293AT, MC33293ATV**

$T_J$ = –40° to +150°C, Case 821D, C

The MC33293AT is a monolithic quad low–side switching device having CMOS logic, bipolar/ CMOS analog circuitry, and DMOS power FETs. All inputs are CMOS compatible. Each independent output is internally clamped to 65 V, current limited to ≥ 3.0 A, and has an $r_{DS(on)}$ of ≤ 0.25 Ω with $V_{PWR}$ ≥ 9.0 V and may be paralleled to lower $r_{DS(on)}$. $\overline{\text{Fault}}$ output reports existence of open loads (outputs "On" or "Off"), shorted loads, and over temperature condition of outputs. A shorted load condition will shut off only the specific output involved while allowing other outputs to operate normally. An overvoltage condition will shut off all outputs for the overvoltage duration. A single/dual mode select pin allows either independent input/output operation or paired output operation.



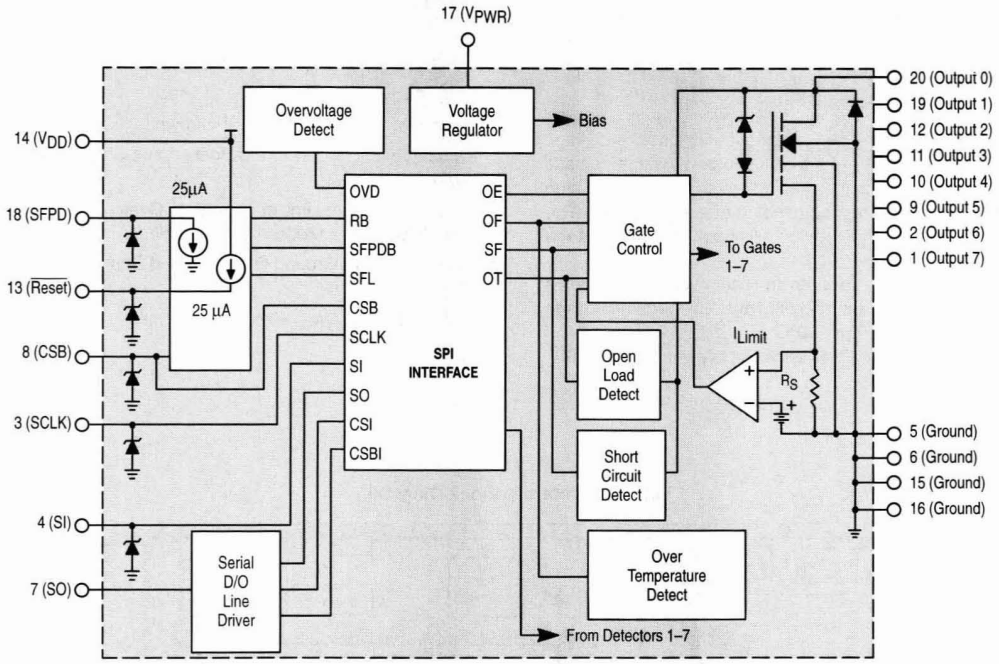
# Octal Serial Switch

**MC33298P, MC33298DW**

$T_J$ = –40° to +150°C, Case 738, 751E

The MC33298 is a monolithic eight output low–side switch with 8–bit serial input control. Incorporates CMOS logic, bipolar/CMOS analog circuitry, and DMOS power FETs. All inputs are CMOS compatible. It is designed to interface to a microcontroller and switch inductive or incandescent loads.

Each independent output is internally clamped to 55 V, current limited to ≥ 3.0 A, and has an $r_{DS(on)}$ of ≤ 0.45 Ω with $V_{PWR}$ ≥ 9.0 V. This device has low standby current, cascadable fault status reporting, output diagnostics, and shutdown for each output.

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# Dual High–Side Switch

**MC33143DW**

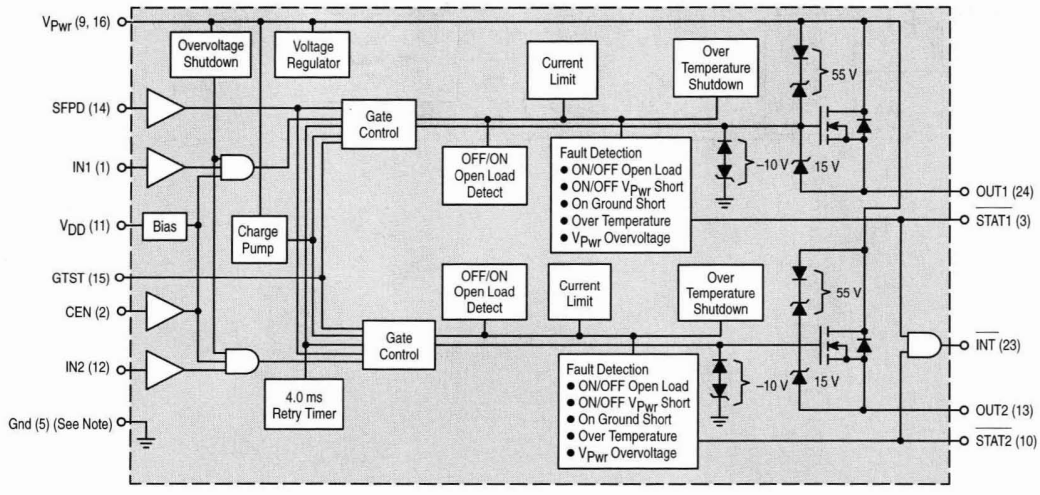
$T_A$ = –40° to +125°C, Case 751E

The MC33143 is a dual high–side switch designed for solenoid control in harsh automotive applications, but is well suited for other environments. The device can also be used to control small motors and relays as well as solenoids. The MC33143 incorporates SMARTMOS™ technology, with CMOS logic, bipolar/MOS analog circuitry, and DMOS power outputs. An internal charge pump is incorporated for efficient gate enhancement of the internal high–side power output devices. The outputs are designed to provide current to low impedance solenoids. The MC33143 provides individual output fault status reporting along with internal Overcurrent and Over Temperature protection. The device also has Overvoltage protection, with automatic recovery, which "globally" disables both outputs for the duration of an Overvoltage condition. Each output has individual Overcurrent and Over Temperature shutdown with automatic retry recovery. Outputs are enabled with a CMOS logic high signal applied to an input to providing true logic control. The outputs, when turned on, provide full supply (battery) voltage across the solenoid coil.

The MC33143 is packaged in an economical 24 pin surface mount power package and specified over an operating voltage of 5.5 V ≤ $V_{Pwr}$ < 26 V for –40°C ≤ $T_A$ ≤ 125°C.

- Designed to Operate Over Wide Supply Voltages of 5.5 V to 26 V
- Dual High–Side Outputs Clamped to –10 V for Driving Inductive Loads
- Internal Charge Pump for Enhanced Gate Drive
- Interfaces Directly to a Microcontroller with Parallel Input Control
- Outputs Current Limited to 3.0 A to 6.0 A for Driving Incandescent Loads
- Chip Enable "Sleep Mode" for Power Conservation
- Individual Output Status Reporting
- $\overline{\text{Fault}}$ Interrupt Output for System Interrupt Use
- Output ON or OFF Open Load Detection
- Overvoltage Detection and Shutdown
- Output Over Temperature Detection and Shutdown with Automatic Retry
- Sustained Current Limit or Immediate Overcurrent Shutdown Output Modes
- Output Short to Ground Detection and Shutdown with Automatic Retry
- Output Short to $V_{Pwr}$ Detection

**Simplified Internal Block Diagram**



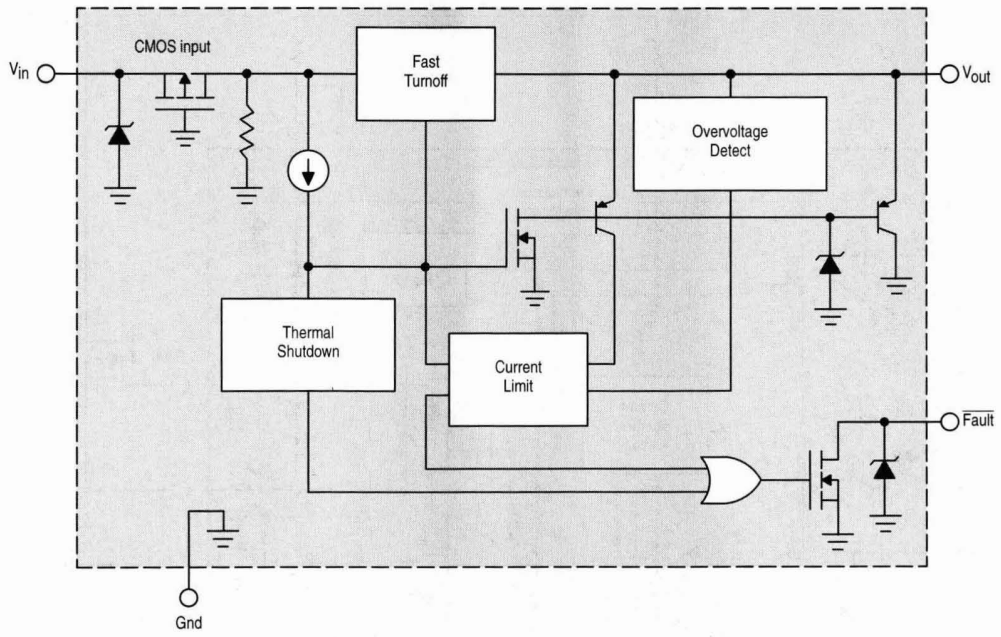

**NOTE:** Pins 5, 6, 7, 8, 17, 18, 19 and 20 should all be grounded so as to provide electrical as well as thermal heatsinking of the device.

## Low Side Protected Switch

**MC3392T, T–1, DW**

$T_J$ = –40° to +150°C,
Case 221A, 314D, 751G

Single low side protected switch with fault reporting capability. Input is CMOS compatible. Output is short circuit protected to 1.0 A minimum with a unique current fold–back feature. Device has internal output clamp for driving inductive loads with overcurrent, overvoltage, and thermal protection. When driving a moderate load, the MC3392 performs as an extremely high gain, low saturation Darlington transistor having a CMOS input characteristic with added protection features. In some applications, the three terminal version can replace industry standard TIP100/101 NPN power Darlington transistors.

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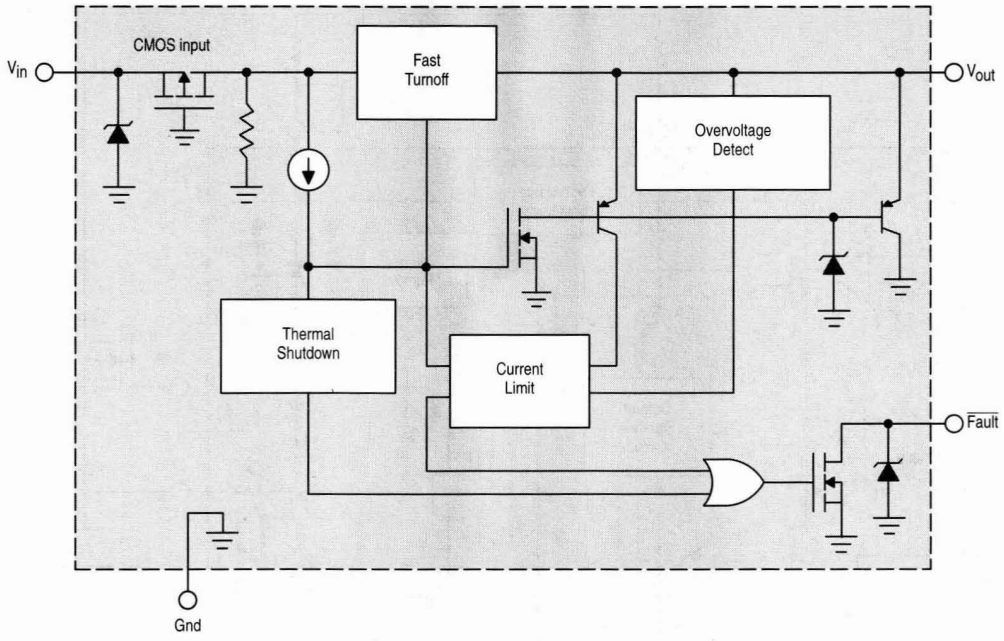
## Low Side Protected Switch

**MC3392T, T–1, DW**

$T_J$ = –40° to +150°C,
Case 221A, 314D, 751G

Single low side protected switch with fault reporting capability. Input is CMOS compatible. Output is short circuit protected to 1.0 A minimum with a unique current fold–back feature. Device has internal output clamp for driving inductive loads with overcurrent, overvoltage, and thermal protection. When driving a moderate load, the MC3392 performs as an extremely high gain, low saturation Darlington transistor having a CMOS input characteristic with added protection features. In some applications, the three terminal version can replace industry standard TIP100/101 NPN power Darlington transistors.

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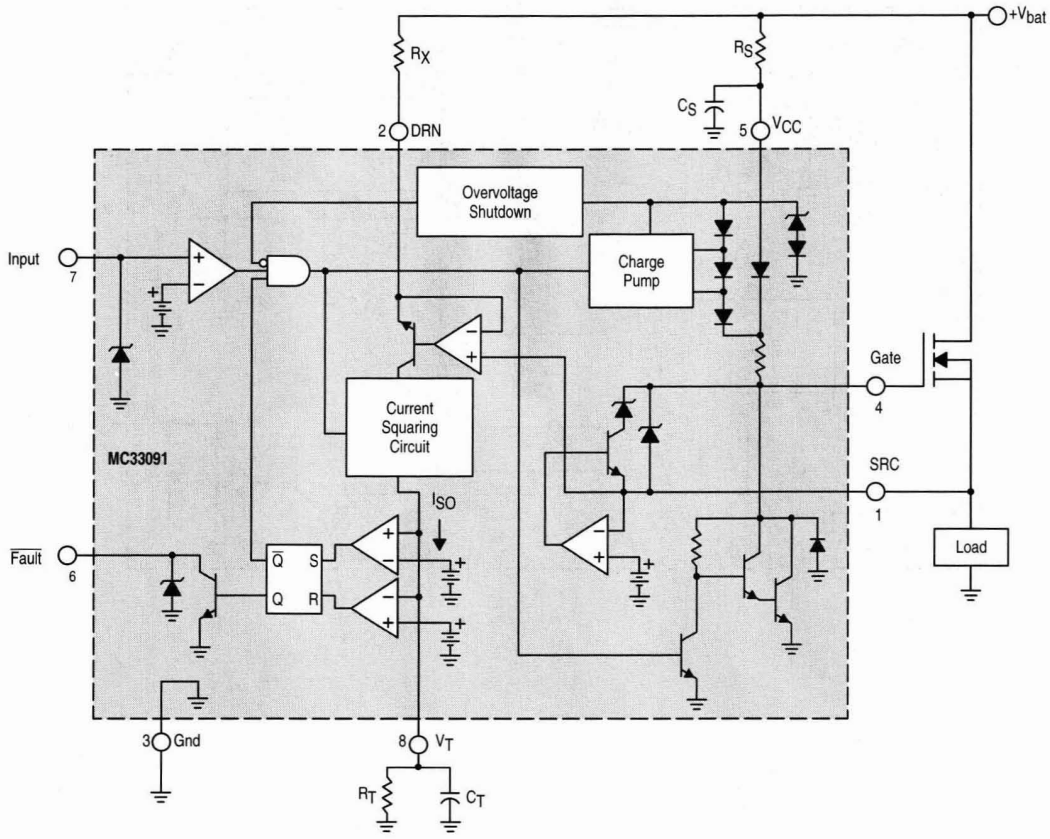
## High Side TMOS Driver

**MC33091AP, AD**

$T_J$ = –40° to +150°C, Case 626, 751

Offers an economical solution to drive and protect N–channel power TMOS devices used in high side switching configurations. Unique device monitors load resulting $V_{DS}$. TMOS voltage to produce a proportional current used to drive an externally programmed over current timer circuit to protect the TMOS device from shorted load conditions. Timer can be programmed to accommodate driving incandescent loads. Few external components required to drive a wide variety of N–channel TMOS devices. A $\overline{\text{Fault}}$ output is made available through the use of an open collector NPN transistor requiring a single pull–up resistor for operation. Input is CMOS compatible. Device uses ≤ 3.0 µA standby current and has an internal charge pump requiring no external components for operation.

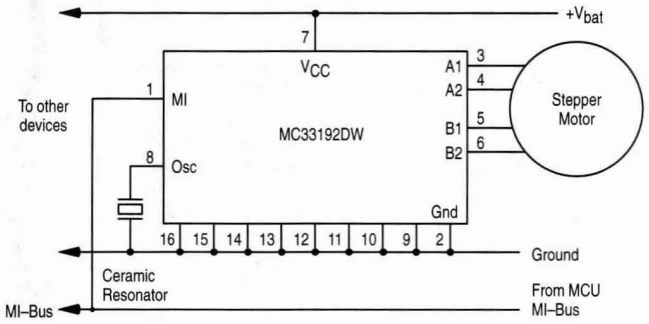


## MI–Bus Interface Stepper Motor Controller

**MC33192DW**

$T_J$ = –40° to +100°C, Case 751G

Intended to control loads in harsh automotive environments using a serial communication bus. Can provide satisfactory real time control of up to eight stepper motors using MI–Bus protocol. Use of MI–Bus offers a noise immune system solution for difficult applications involving relays and motors. The stepper motor controller provides four phase signals to drive two phase motors in either half of full–step modes. Designed to interface to a microprocessor with minimal amount of wiring, affording an economical and versatile system.



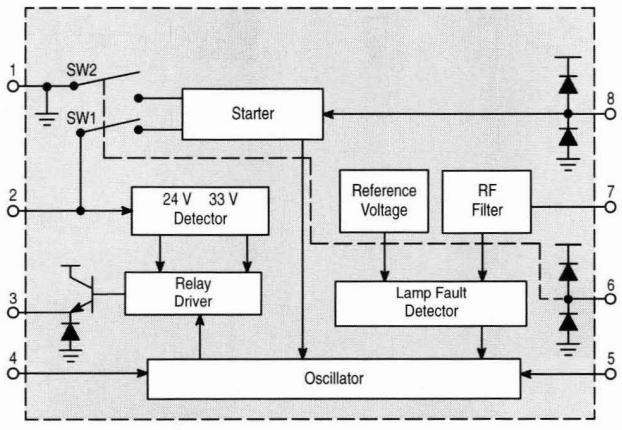

## Automotive Direction Indicator

**MC33193P, D**

$T_A$ = –40° to +125°C, Case 626, 751

The MC33193 is a new generation industry standard UAA1041 "Flasher". It has been developed for enhanced EMI sensitivity, system reliability, and improved wiring simplification. The MC33193 is pin compatible with the UAA1041 and UAA1041B in the standard application configuration as shown in Figure 9, without lamp short circuit detection and using a 20 mΩ shunt resistor. The MC33193 has a standby mode of operation requiring very low standby supply current and can be directly connected to the vehicle's battery. It includes a RF filter on the Fault detection pin (Pin 7) for EMI purposes. Fault detection thresholds are reduced relative to those of the UAA1041 allowing a lower shunt resistance value (20 mΩ) to be use.

- Pin Compatible with the UAA1041
- Defective Lamp Detection Threshold
- RF Filter for EMI Purposes
- Load Dump Protection
- Double Battery Capability for Jump Start Protection
- Internal Free Wheeling Diode Protection
- Low Standby Current Mode

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# Automotive Wash Wiper Timer

**MC33197AD**

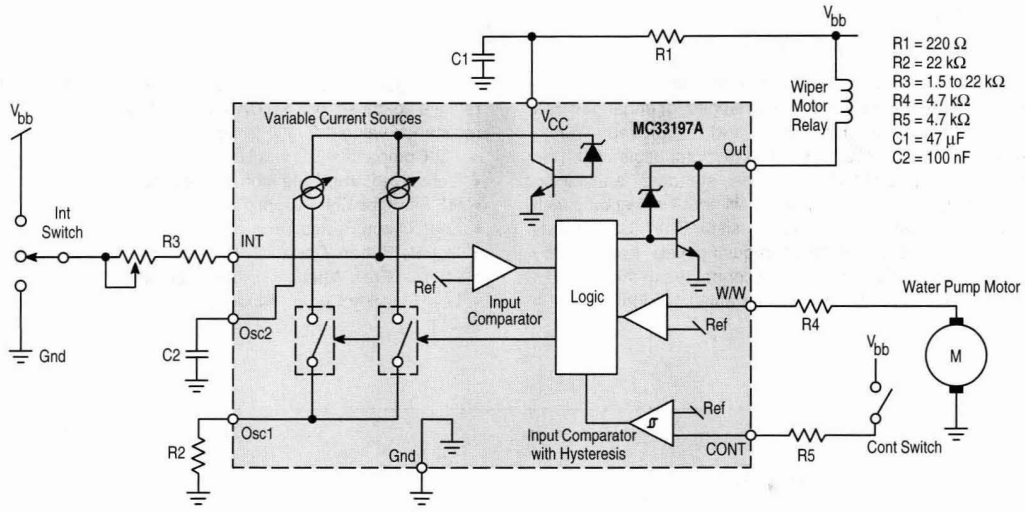
$T_A$ = –40° to +105°C, Case 751

**MC33197AP**

$T_A$ = –40° to +125°C, Case 626

The MC33197A is a standard wiper timer control device designed for harsh automotive applications. The device can perform the intermittent, after wash, and continuous wiper timer functions. It is designed to directly drive a wiper motor relay. The MC33197A requires very few external components for full system implementation. The intermittent control pin can be switched to ground or $V_{bat}$ to meet a large variety of possible applications. The intermittent timing can be fixed or adjustable via an external resistor. The MC33197A is built using bipolar technology and parametrically specified over the automotive ambient temperature range and 8.0 to 16 V supply voltage. The MC33197A can operate in both front and rear wiper applications.

- Adjustable Time Interval of Less Than 500 ms to More Than 30 s
- Intermittent Control Pin Can Be Switched to Ground or $V_{bat}$
- Adjustable After Wipe Time
- Priority to Continuous Wipe
- Minimum Number of Timing Components
- Integrated Relay Driver With Free Wheeling Protection Diode
- Operating Voltage Range From 8.0 to 16 V
- For Front Wiper and Rear Wiper Window Applications



# Automotive ISO 9141 Serial Link Driver

**MC33199D**

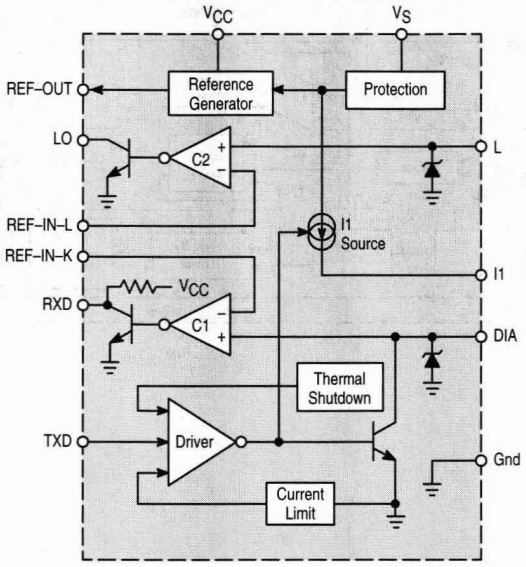
$T_A$ = –40° to +125°C, Case 751A

The MC33199D is a serial interface circuit used in diagnostic applications. It is the interface between the microcontroller and the special K and L Lines of the ISO diagnostic port. The MC33199D has been designed to meet the "Diagnosis System ISO 9141" specification.

The device has a bi–directional bus K Line driver, fully protected against short circuits and over temperature. It also includes the L Line receiver, used during the wake up sequence in the ISO transmission.

The MC33199 has a unique feature which allows transmission baud rate up to 200 k baud.

- Electrically Compatible with Specification "Diagnosis System ISO 9141"
- Transmission Speed Up to 200 k Baud
- Internal Voltage Reference Generator for Line Comparator Thresholds
- TXD, RXD and LO Pins are 5.0 V CMOS Compatible
- High Current Capability of DIA Pin (K Line)
- Short Circuit Protection for the K Line Input
- Over Temperature Shutdown with Hysteresis
- Large Operating Range of Driver Supply Voltage
- Full Operating Temperature Range
- ESD Protected Pins

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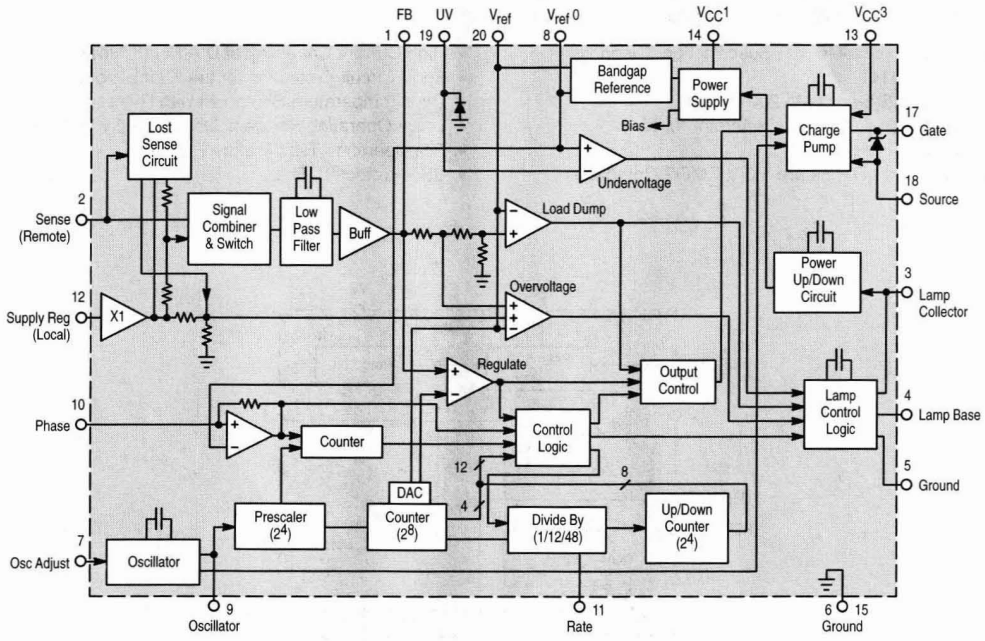
# Alternator Voltage Regulator

**MC33092DW**

$T_J$ = –40° to +125°C, Case 751D

Provides voltage regulation and load response control in diode rectified 12 V alternator charging systems. Provides externally programmed load response control of the alternator output current to eliminate engine speed hunting and vibration due to sudden electrical loads. Monitors and compares the system battery voltage to an externally programmed set point value and pulse width modulates an N–channel MOSFET transistor to control the average alternator field current. In addition, has duty cycle limiting, under/overvoltage and phase detection (broken belt) protective features.

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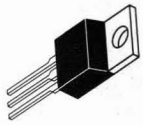
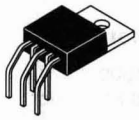
# Automotive Electronic Circuits Package Overview

CASE 29
Z SUFFIX



CASE 221A
T SUFFIX



CASE 314A
TH SUFFIX

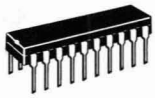
CASE 314B
TV SUFFIX

CASE 314D
T, T–1 SUFFIX

CASE 369
DT–1 SUFFIX

CASE 369A
DT SUFFIX

CASE 626
P, NO SUFFIX



CASE 738
P SUFFIX

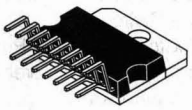
CASE 751
D SUFFIX

CASE 751A
D SUFFIX

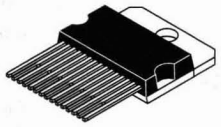
CASE 751D
DW SUFFIX

CASE 751E
DW SUFFIX

CASE 751G
DW SUFFIX



CASE 821C
TV SUFFIX



CASE 821D
T SUFFIX

CASE 936
D2T SUFFIX

CASE 936A
D2T SUFFIX

10

# Device Listing

## Voltage Regulators


| Device | Function | Page |
|---|---|---|
| **LM2931 Series** | Low Dropout Voltage Regulators | See Chapter 3 |
| **MCCF33095, MC33095** | Integral Alternator Regulator | 10–134 |


## Electronic Ignition


| | | |
|---|---|---|
| **MC3334, MCC3334, MCCF3334** | High Energy Ignition Circuit | 10–15 |
| **MC79076, MCCF79076** | Electronic Ignition Control Circuit | 10–131 |
| **MCCF33093** | Ignition Control Flip–Chip | 10–132 |
| **MCCF33094** | Ignition Control Flip–Chip | 10–133 |


## Special Functions


| | | |
|---|---|---|
| **MC3392** | Low Side Protected Switch | 10–19 |
| **MC3399** | Automotive Half–Amp High–Side Switch | 10–28 |
| **MC33091A** | High–Side TMOS Driver | 10–31 |
| **MC33092** | Alternator Voltage Regulator | 10–45 |
| **MC33143** | Dual High–Side Switch | 10–53 |
| **MC33192** | Mi-Bus Interface Stepper Motor Controller | 10–60 |
| **MC33193** | Automotive Direction Indicator | 10–71 |
| **MC33197A** | Automotive Wash Wiper Timer | 10–78 |
| **MC33199** | Automotive ISO 9141 Serial Link Driver | 10–83 |
| **MC33293A** | Quad Low Side Switch | 10–94 |
| **MC33298** | Octal Serial Switch and Serial Peripheral Interface I/O | 10–109 |
| **TCA5600/TCF5600** | Universal Microprocessor Power Supply/Controllers | See Chapter 3 |
| **TCF6000** | Peripheral Clamping Array | 10–144 |
| **UAA1041B** | Automotive Direction Indicator | 10–148 |

MOTOROLA

# MC3334
# MCC3334
# MCCF3334

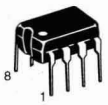
## High Energy Ignition Circuit

This device is designed to use the signal from a reluctor type ignition pickup to produce a well controlled output from a power Darlington output transistor.

- Very Low Peripheral Component Count
- No Critical System Resistors
- Wide Supply Voltage Operating Range (4.0 V to 24 V)
- Overvoltage Shutdown (30 V)
- Dwell Automatically Adjusts to Produce Optimum Stored Energy without Waste
- Externally Adjustable Peak Current
- Available in Chip and Flip–Chip Form
- Transient Protected Inputs and Outputs

**HIGH ENERGY IGNITION CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**



**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage–Steady State<br>Transient 300 ms or less | $V_{bat}$ | 24<br>90 | V |
| Output Sink Current–Steady State<br>Transient 300 ms or less | $I_{O(Sink)}$ | 300<br>1.0 | mA<br>A |
| Junction Temperature | $T_{J(max)}$ | 150 | °C |
| Operating Temperature Range | $T_A$ | –40 to +125 | °C |
| Storage Temperature Range | Tstg | –65 to +150 | °C |
| Power Dissipation, Plastic Package, Case 626<br>Derate above 25°C | $P_D$ | 1.25<br>10 | W<br>mW/°C |

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3334P | $T_A$ = – 40° to +125°C | Plastic DIP |
| MC3334D | | SO–8 |
| MCC3334 | | Chip |
| MCCF3334 | | Flip–Chip |

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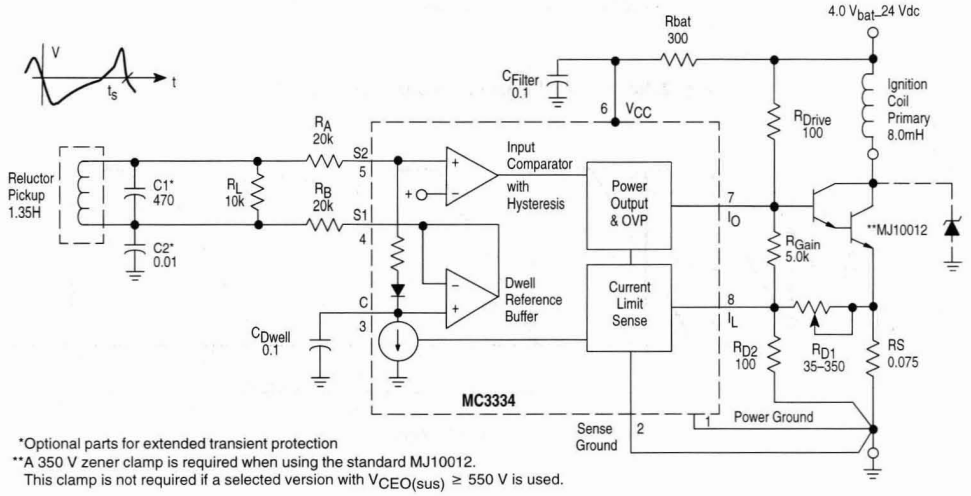
**Figure 1. Block Diagram and Typical Application**

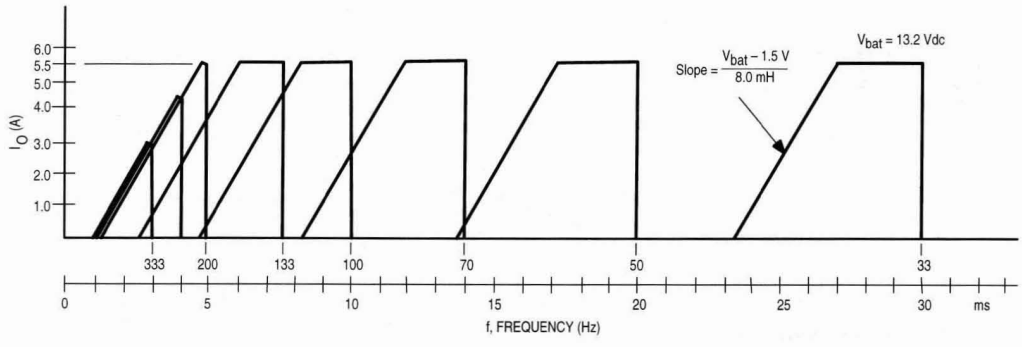



*Optional parts for extended transient protection
**A 350 V zener clamp is required when using the standard MJ10012.
This clamp is not required if a selected version with $V_{CEO(sus)}$ ≥ 550 V is used.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = –40° to +125°C, $V_{bat}$ = 13.2 Vdc, circuit of Figure 1, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Internal Supply Voltage, Pin 6 | $V_{CC}$ | | | | Vdc |
| $V_{bat}$ = 4.0 Vdc | | – | 3.5 | – | |
| 8.0 Vdc | | – | 7.2 | – | |
| 12.0 | | – | 10.4 | – | |
| 14.0 | | – | 11.8 | – | |
| Ignition Coil Current Peak, Cranking RPM 2.0 Hz to 27 Hz | $I_{o(pk)}$ | | | | A pk |
| $V_{bat}$ = 4.0 Vdc | | 3.0 | 3.4 | – | |
| 6.0 | | 4.0 | 5.2 | – | |
| 8.0 | | 4.6 | 5.3 | – | |
| 10.0 | | 5.1 | 5.4 | – | |
| Ignition Coil Current Peak, Normal RPM | $I_{o(pk)}$ | | | | A pk |
| Frequency = 33 Hz | | 5.1 | 5.5 | – | |
| 133 Hz | | 5.1 | 5.5 | – | |
| 200 Hz | | 4.2 | 5.4 | – | |
| 267 Hz | | 3.4 | 4.4 | – | |
| 333 Hz | | 2.7 | 3.4 | | |
| Ignition Coil On–Time, Normal RPM Range | $t_{on}$ | | | | ms |
| Frequency = 33 Hz | | – | 7.5 | 14.0 | |
| 133 Hz | | – | 5.0 | 5.9 | |
| 200 Hz | | – | 4.0 | 4.6 | |
| 267 Hz | | – | 3.0 | 3.6 | |
| 333 Hz | | – | 2.3 | 2.8 | |
| Shutdown Voltage | $V_{bat}$ | 25 | 30 | 35 | Vdc |
| Input Threshold (Static Test) | $V_{S2}$–$V_{S1}$ | | | | mVdc |
| Turn–on | | – | 360 | – | |
| Turn–off | | – | 90 | – | |
| Input Threshold Hysteresis | $V_{S2}$–$V_{S1}$ | 75 | – | – | mVdc |
| Input Threshold (Active Operation) | $V_{S2}$ | | | | Vdc |
| Turn–on | | – | 1.8 | – | |
| Turn–off | | – | 1.5 | – | |
| Total Circuit Lag from $t_s$ (Figure 1) until Ignition Coil Current Falls to 10% | | – | 60 | 120 | µs |
| Ignition Coil Current Fall Time (90% to 10%) | | – | 4.0 | – | µs |
| Saturation Voltage IC Output (Pin 7) ($R_{DRIVE}$ = 100 Ω) | $V_{CE(sat)}$ | | | | mVdc |
| $V_{bat}$ = 10 Vdc | | – | 120 | – | |
| 30 Vdc | | – | 280 | – | |
| 50 Vdc | | – | 540 | – | |
| Current Limit Reference, Pin 8 | $V_{ref}$ | 120 | 160 | 190 | mVdc |

**Figure 2. Ignition Coil Current versus Frequency/Period**

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## CIRCUIT DESCRIPTION

The MC3334 high energy ignition circuit was designed to serve aftermarket Delco five–terminal ignition applications. This device, driving a high voltage Darlington transistor, offers an ignition system which optimizes spark energy at minimum power dissipation. The IC is pinned–out to permit thick film or printed circuit module design without any crossovers.

The basic function of an ignition circuit is to permit build–up of current in the primary of a spark coil, and then to interrupt the flow at the proper firing time. The resulting flyback action in the ignition coil induces the required high secondary voltage needed for the spark. In the simplest systems, fixed dwell angle produces a fixed duty cycle, which can result in too little stored energy at high RPM, and/or wasted power at low RPM. The MC3334 uses a variable DC voltage reference, stored on $C_{Dwell}$, and buffered to the bottom end of the reluctor pickup (S1) to vary the duty cycle at the spark coil. At high RPM, the MC3334 holds the output "off" for approximately 1.0 ms to permit full energy discharge from the previous spark; then it switches the output Darlington transistor into full saturation. The current ramps up at a slope dictated by $V_{bat}$ and the coil L. At very high RPM the peak current may be less than desired, but it is limited by the coil itself.

As the RPM decreases, the ignition coil current builds up and would be limited only by series resistance losses. The MC3334 provides adjustable peak current regulation sensed by $R_S$ and set by $R_{D1}$, in this case at 5.5 A, as shown in Figure 2. As the RPM decreases further, the coil current is held at 5.5 A for a short period. This provides a reserve for sudden acceleration, when discharge may suddenly occur earlier than expected. The peak hold period is about 20% at medium RPM, decreasing to about 10% at very low RPM. (Note: 333 Hz = 5000 RPM for an eight cylinder four stroke engine.) At lower $V_{bat}$, the "on" period automatically stretches to accommodate the slower current build–up. At very low $V_{bat}$ and low RPM, a common condition during cold starting, the "on" period is nearly the full cycle to permit as much coil current as possible.

The output stage of the IC is designed with an OVP circuit which turns it on at $V_{bat} \approx 30$ V ($V_{CC} \approx 22$ V), holding the output Darlington off. This protects the IC and the Darlington from damage due to load dump or other causes of excessive $V_{bat}$.

### Component Values

Pickup – series resistance = 800 Ω ± 10% @ 25°C
inductance = 1.35 H @ 1.0 kHz @ 15 Vrms

Coil – leakage L = 0.6 mH
primary R = 0.43 Ω ± 5% @ 25°C
primary L = 7.5 mH to 8.5 mH @ 5.0 A

$R_L$ – load resistor for pickup = 10 kΩ ± 20%

$R_A$, $R_B$ – input buffer resistors provide additional transient protection to the already clamped inputs = 20 k ± 20%

C1, C2 – for reduction of high frequency noise and spark transients induced in pick–up and leads; optional and non–critical

$R_{bat}$ – provides load dump protection (but small enough to allow operation at $V_{bat}$ = 4.0 V) = 300 Ω ± 20%

$C_{Filter}$ – transient filter on $V_{CC}$, non–critical

$C_{Dwell}$ – stores reference, circuit designed for 0.1 μF ± 20%

$R_{Gain}$ – $R_{Gain}/R_{D1}$ sets the DC gain of the current regulator = 5.0 k ± 20%

$R_{D2}$ – $R_{D2}/R_{D1}$ set up voltage feedback from $R_S$

$R_S$ – sense resistor (PdAg in thick film techniques) = 0.075 Ω ± 30%

$R_{Drive}$ – low enough to supply drive to the output Darlington, high enough to keep $V_{CE(sat)}$ of the IC below Darlington turn–on during load dump = 100 Ω ± 20%, 5.0 W

$R_{D1}$ – starting with 35 Ω assures less than 5.5 A, increasing as required to set 5.5 A

$$R_{D1} = \frac{I_{O(pk)}\, R_S - V_{ref}}{\frac{V_{ref}}{R_{D2}} - \frac{1.4}{R_{Gain}}} - (\approx 100\ \Omega)$$

### General Layout Notes

The major concern in the substrate design should be to reduce ground resistance problems. The first area of concern is the metallization resistance in the power ground to module ground and the output to the $R_{drive}$ resistor. This resistance directly adds to the $V_{CE(sat)}$ of the IC power device and if not minimized could cause failure in load dump. The second concern is to reference the sense ground as close to the ground end of the sense resistor as possible in order to further remove the sensitivity of ignition coil current to ground I.R. drops.

All versions were designed to provide the same pin–out order viewed from the top (component side) of the board or substrate. This was done to eliminate conductor cross–overs. The standard MC3334 plastic device is numbered in the industry convention, counter–clockwise viewed from the top, or bonding pad side. The MCCF3334 "flip" or "bump" chip is made from reversed artwork, so it is numbered clockwise viewed from its bump side. Since this chip is mounted face down, the resulting assembly still has the same counter–clockwise order viewed from above the component surface. All chips have the same size and bonding pad spacing. See Figure 4 for dimensions.

**Figure 3. Internal Schematic**

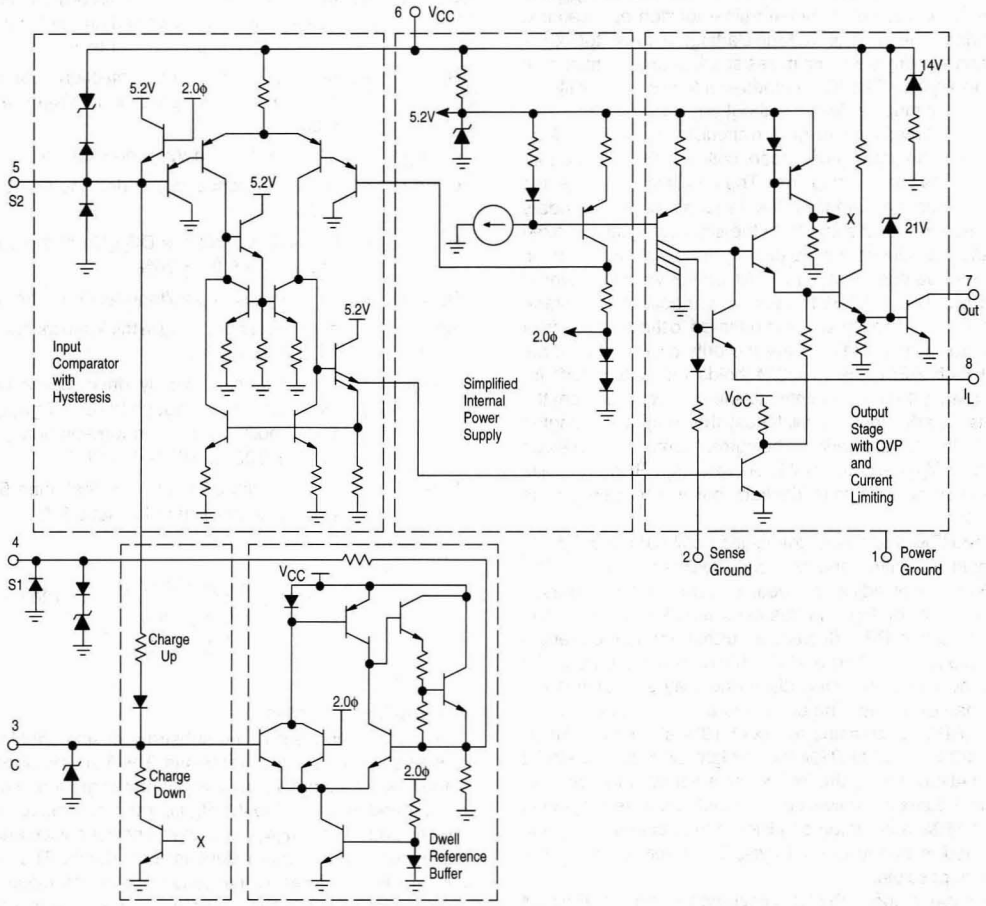
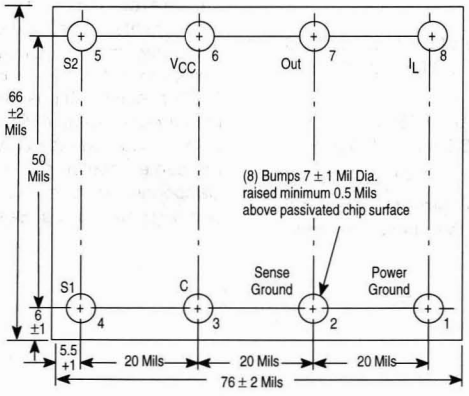



**Figure 4. MCCF3334 Ignition Circuit Bump Side View**

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MOTOROLA

# MC3392

# Low Side Protected Switch

**LOW SIDE PROTECTED SWITCH**

**SEMICONDUCTOR TECHNICAL DATA**

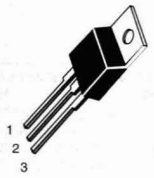
The MC3392 is a low side protected switch designed for use in harsh automotive applications which require the capability of handling high voltages attributed to load and field dump transients, in addition to reverse and double battery conditions. The three terminal TO–220 is intended to replace power Darlington transistors in new and existing switching applications when taking into account the CMOS input levels required by the MC3392. It offers improved functionality and ruggedness over power Darlingtons while retaining the same package and pin configuration, and can be used as a replacement in many applications using the industry standard TIP100/101 NPN power Darlington transistor.

The five–terminal TO–220 has the added feature of having a $\overline{\text{Fault}}$ output (active low) which will indicate the existence of an over temperature, over–voltage or current limit condition, including an output short to ground.

When driving a moderate load, the MC3392 performs as an extremely high gain, low saturation Darlington transistor having CMOS input levels. The primary advantage of the MC3392 over a Darlington transistor is the additional protection afforded the device and load when driving difficult or faulty loads. This device incorporates unique internal current limit and thermal protection circuitry to safeguard itself and the associated load from catastrophic failure.

The MC3392 is available in a three and five–lead TO–220 package; the five–lead having the added diagnostic feature. The full featured MC3392 is also available in a 16 pin wide body SOIC plastic power package.

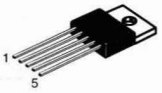
- Designed for Automotive Applications
- Can Be Used as a Replacement for TIP100/101 NPN Power Darlingtons
- Drives Inductive Loads without External Clamp Circuitry
- Withstands Negative and Positive Transient Voltages
- Low ON Voltage
- CMOS Logic Compatible Input
- Over Current, Overvoltage, and Thermal Protection
- Extended Operating Temperature Range
- $\overline{\text{Fault}}$ Output




Pin 1. Input
2. Output
3. Ground

(Heatsink surface connected to Pin 3)

**T SUFFIX**
PLASTIC PACKAGE
CASE 221A
(TO–220)



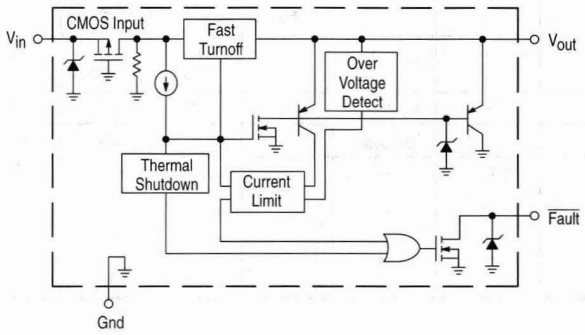

Pin 1. Input
2. $\overline{\text{Fault}}$
3. Ground
4. NC
5. Output

**T–1 SUFFIX**
PLASTIC PACKAGE
CASE 314D
(TO–220)

Pin 1. NC
2. NC
3. NC
4. Output
5. Input
6. $\overline{\text{Fault}}$
7. NC
8. NC
9–16. Ground

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751G
SOP(8+8)L

**Simplified Block Diagram**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3392T | $T_A$ = – 40° to +125°C | Plastic Power |
| MC3392T–1 | | Plastic Power |
| MC3392DW | | SOP(8+8)L |

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**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Input Voltage Range | $V_{in}$ | – 0.5 to + 6.5 | V |
| Output Transient Breakdown Voltage – Forward<br>– Reverse | $V_{BF}$<br>$V_{BR}$ | + 60<br>– 80 | V |
| Short Circuit Current | $I_{SC}$ | 2.2 | A |
| Output Avalanche Energy (Note 1) | $E_{max}$ | 60 | mJ |
| Minimum ESD Voltage Capability (Note 2) | ESD | 2000 | V |
| Operating Junction Temperature<br>Internally Limited (Note 3) | $T_J$ | 150 | °C |
| Storage Temperature | $T_{stg}$ | – 65 to +150 | °C |
| Operating Ambient Temperature Range | $T_A$ | – 40 to +125 | °C |
| Thermal Resistance (Notes 4, 5)<br>TO–220: Junction–to–Ambient<br>Junction–to–Case<br>SOP: Junction–to–Ambient<br>Junction–to–Case | <br>$R_{\theta JA}$<br>$R_{\theta JC}$<br>$R_{\theta JA}$<br>$R_{\theta JC}$ | <br>62.5<br>2.5<br>118<br>59 | °C/W |

**NOTES:** 1. Capability for both positive and negative repetitive transient pulses.
2. ESD testing performed in accordance with Human Body Model ($C_{Zap}$ = 100 pF, $R_{Zap}$ = 1500 Ω).
3. This device incorporates internal circuit techniques which do not allow the internal junction temperature to reach destructive temperatures.
4. The thermal resistance case is considered to be a point located near the center of the tab and plastic body of the TO–220 or a point on one of the heatsink leads (Pins 9 to 16) of the SOP.
5. The SOP thermal information is based on simulation data.

**ELECTRICAL CHARACTERISTICS** (Limit values are noted under conditions: – 40°C ≤ $T_A$ ≤ +125°C. Typical denotes calculated mean value derived from 25°C parametric data, unless otherwise noted.)

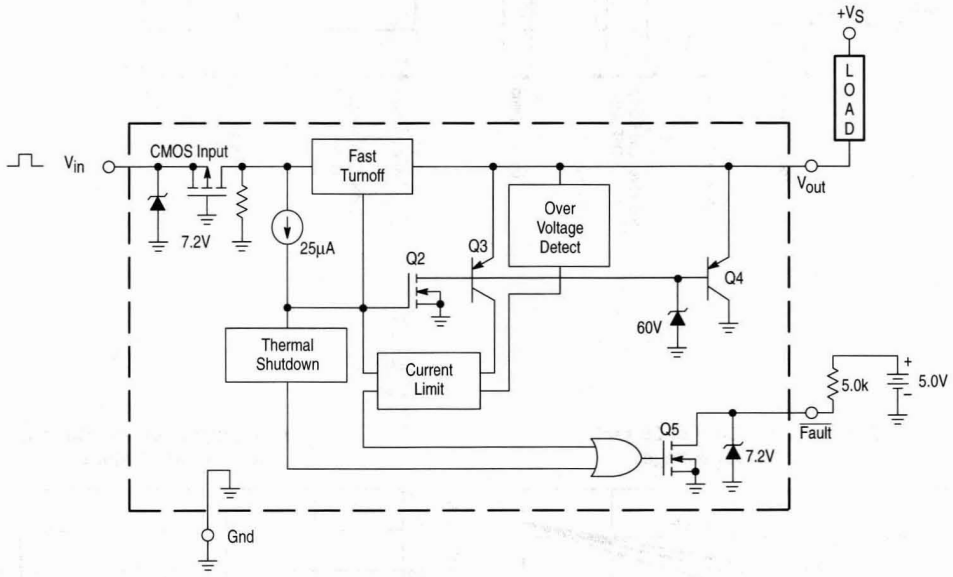
| Characteristics | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Input Control Current<br>$V_{in}$ = 1.0 V<br>$V_{in}$ = 4.0 V<br>$V_{in}$ = 5.0 V | 3 | $I_{in}$ | <br>–<br>–<br>– | <br>0.2<br>230<br>260 | <br>10<br>350<br>500 | µA |
| Input Voltage High (On)<br>Input Voltage Low (Off) | 7 | $V_{IH}$<br>$V_{IL}$ | 4.0<br>– | 2.0<br>2.0 | –<br>1.0 | V |
| Output Leakage Current<br>$+V_S$ = 28 V, $R_L$ = 0 | 4 | $I_L$ | – | 1.3 | 100 | µA |
| Output Short Circuit Current<br>$+V_S$ = 14 V, $R_L$ = 0 | 5 | $I_{SC}$ | 1.0 | 1.3 | 2.2 | A |
| Output On Voltage ($V_{in}$ = 4.0 V, Note 6)<br>$I_O$ = 400 mA<br>$I_O$ = 800 mA | 6 | $V_{OL}$ | <br>–<br>– | <br>0.95<br>1.1 | <br>1.1<br>1.8 | V |
| Output Clamp Voltage<br>$I_O$ = 100 mA | 8 | $V_{OC}$ | 60 | 70 | 80 | V |
| Reverse Leakage Current<br>$V_{out}$ = –13 V | 9 | $I_{BR}$ | – | –10 | – 30 | mA |
| Fault Output Sink Saturation ($I_{Sink}$ = 100 µA, $V_{in}$ = 5.0 V) | 10 | $V_{DS(sat)}$ | – | 0.3 | 0.4 | V |
| Fault Output Off–State Leakage ($V_{DS}$ = 5.0 V) | | $I_{DS(leak)}$ | – | 0.6 | 100 | µA |
| Turn–On Time<br>10% to 90% of $I_O$ (400 mA Nominal)<br>Turn–Off Time<br>90% to 10% of $I_O$ (400 mA Nominal)<br>Propagation Delay Time<br>Input to Output (Turn–On/Turn–Off, 50%) | 11<br><br>12<br><br>– | $t_r$<br><br>$t_f$<br><br>$t_d$ | <br>–<br><br>–<br><br>– | <br>3.3<br><br>9.7<br><br>3.0 | <br>20<br><br>25<br><br>10 | µA |

**NOTE:** 6. $I_O$ is defined as the output sink current.

**PIN FUNCTION DESCRIPTION**

| Name | Pin Number | | | Description |
|---|---|---|---|---|
| | 3–Pin | 5–Pin | 16–Pin | |
| $V_{in}$ | 1 | 1 | 5 | CMOS compatible input. Pins 1, 2, 3, 7, 8 no connection on 751G. |
| $V_{out}$ | 2 | 5 | 4 | Output to load and battery, protected by a 60 V clamp against inductive load transients. |
| Gnd | 3 | 3 | 9 to 16 | Ground connection. |
| $\overline{Fault}$ | – | 2 | 6 | Fault output pulled low when the IC is operating in a fault state. The open drain output requires a pull–up resistor for normal operation. |

**Figure 1. Representative Block Diagram**




**Definition of Currents and Voltages.** Positive current flow is defined as conventional current flow into the device. Negative current flow is defined as current flow out of the device. All voltages are referenced to ground. Both currents and voltages are specified as absolute (i.e., –10 V is greater than –1.0 V).

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**Figure 2. Fault Output Timing Diagram**

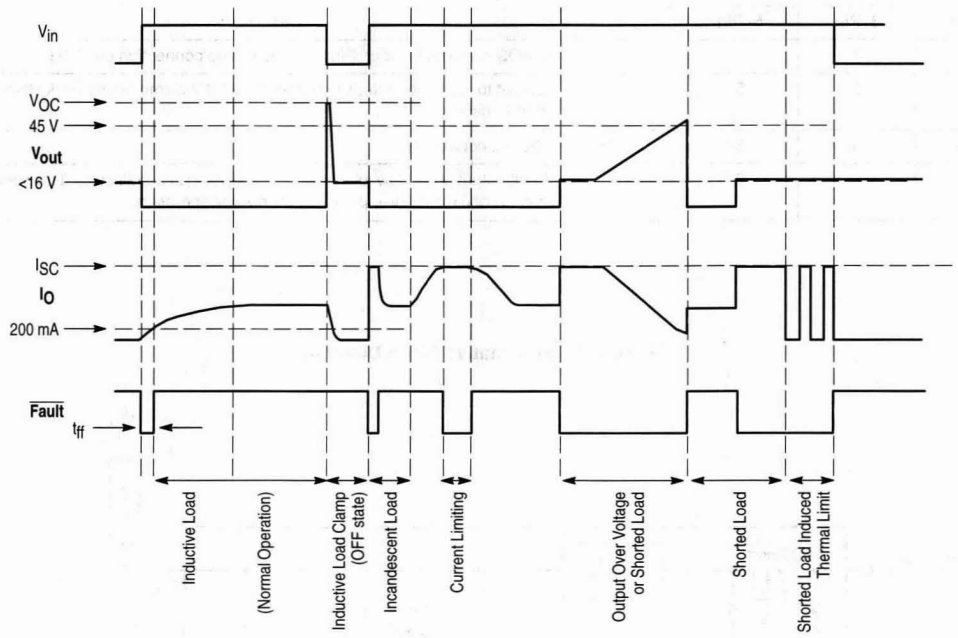


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**Figure 3. Input Control Current versus Input Voltage**

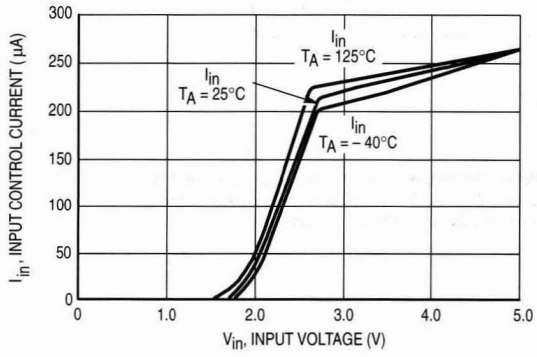


**Figure 4. Output Leakage Current versus Temperature**

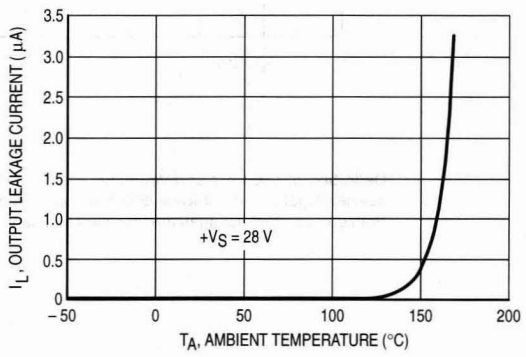

**Figure 5. Output Short Circuit Current versus Temperature**

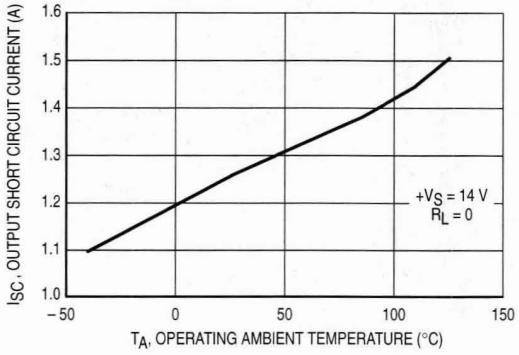


**Figure 6. Output On Voltage versus Temperature**

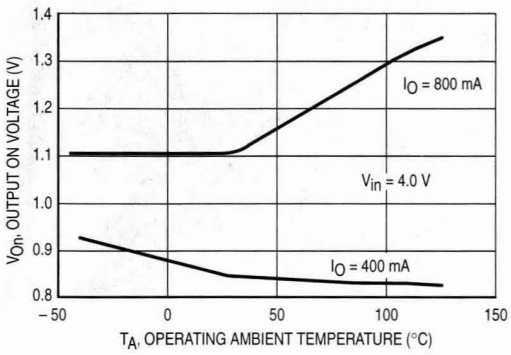


**Figure 7. Input Voltage versus Temperature**

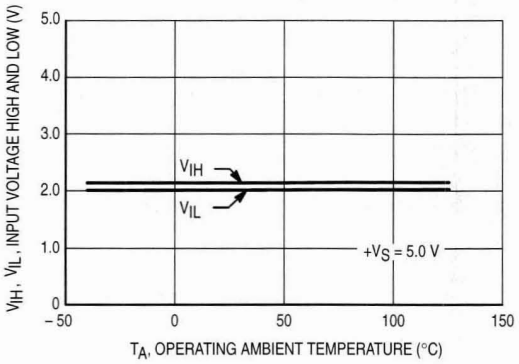


**Figure 8. Output Clamp Voltage versus Temperature**

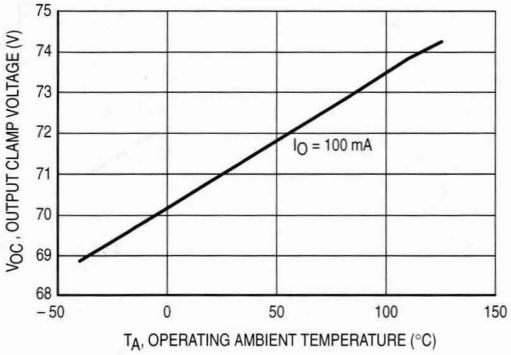


**Figure 9. Reverse Breakdown Voltage versus Temperature**

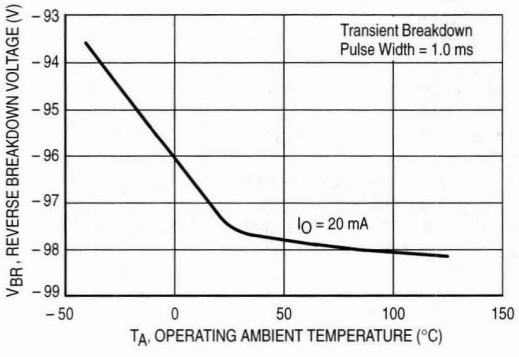


**Figure 10. $\overline{\text{Fault}}$ Output Saturation versus Sink Current**

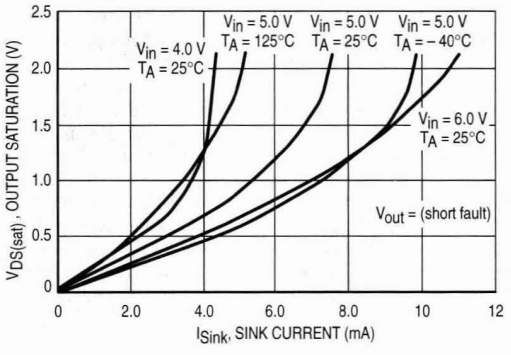


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**Figure 11. Turn–On Waveform**

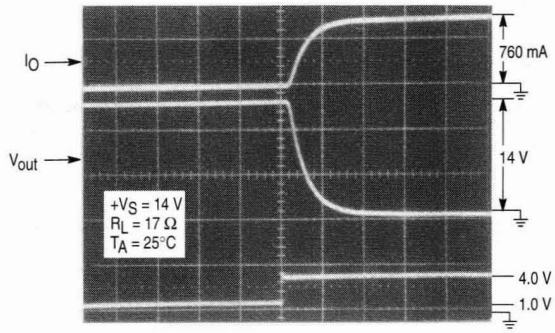



**Figure 12. Turn–Off Waveform**

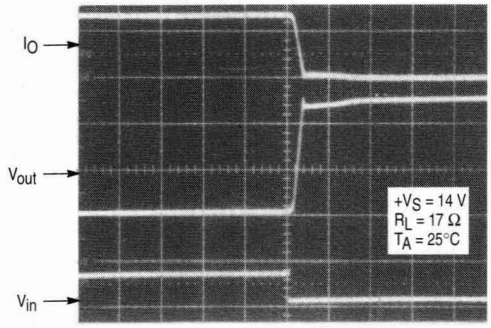



**Figure 13. Output Current versus Supply Voltage**

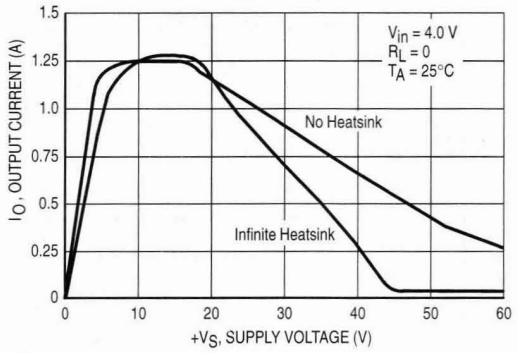
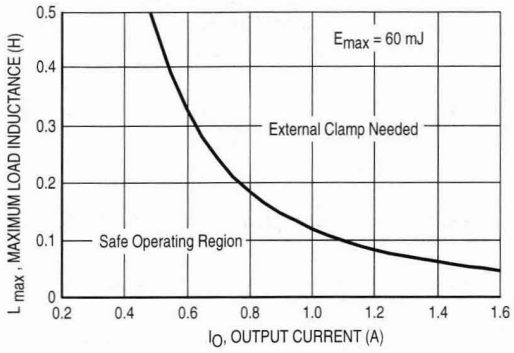



**Figure 14. Maximum Load Inductance versus Output Current**

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## TECHNICAL DISCUSSION

### Introduction

The MC3392 is a low side protected switch incorporating many features making it ideal for use in harsh automotive applications. The protection circuitry of the MC3392 protects not only itself but also the associated load from destructive voltage transients attributed to load and field dump, as well as reverse and double battery conditions found in automotive applications. The MC3392 is unique in that the protection circuitry is internal and does not require additional external protection components for its operation. This makes the device very cost effective because its application utilizes few external components, thus reducing cost and space requirements needed for the system. The MC3392 is extremely effective when used to drive solenoids, as well as incandescent lamp loads. The following description of the device's operation is in reference to the functional blocks of the Representative Block Diagram shown in Figure 1.

### CMOS Input

The input of the MC3392 is CMOS compatible. Input control performs as true logic. When the input ($V_{in}$) is less than 1.0 V the MC3392 switch is in a high impedance or OFF state. When $V_{in}$ is greater than 4.0 V, is in a low impedance or ON state. The switching threshold of the input is approximately 2.0 V and is graphed in Figure 7. With the input at 4.0 V, the input sink current will be approximately 250 μA. In the ON state, the internal protection circuitry is activated and all of the protection features are available for use. In the OFF state, however, it is important to note that none of the protection features are available, with the exception of the internal inductive load clamp. The input pin is afforded a minimum of 2000 V ESD protection (Human Body Model) by virtue of the 7.2 V zener diode.

### Over Temperature Shutdown

Internal Thermal Shutdown Circuitry is provided to protect the MC3392 in the event the Operating Junction Temperature ($T_J$) exceeds 150°C. Typically, Thermal Shutdown will occur at 160° to 170°C. The thermal shutdown sense element is embedded within the output PNP (Q4) in order to afford very fast thermal coupling of Q4 to the sense element. Any rise in temperature due to the ambient is translated directly to Q4 and the sense element. If the junction temperature rises excessively above 150°C, the Thermal Shutdown circuit will turn ON, quickly pulling the gate of Q2 to ground, which pulls the base of Q4 to ground, turning it OFF. In addition, the Thermal Shutdown circuit simultaneously turns Q5 ON and with a suitable pull–up resistor at the $\overline{\text{Fault}}$ pin reports the presence of a fault (logic low). The output PNP will remain OFF until the junction temperature decreases to within the operating range at which time Thermal Shutdown turns OFF, ceasing to hold the gate of Q2 low, turning Q4 back ON. This process will repeat as long as the thermal over load exists. This mode of operation is a nondestructive safety feature of the device and will correct itself real time when the cause of over temperature is removed. A continued over temperature condition will thermally Pulse Width Modulate (PWM) the output and $\overline{\text{Fault}}$ and may be incorrectly interpreted as an oscillating load if one does not consider the simultaneous performance of the $\overline{\text{Fault}}$ pin.

### Current Limit

The MC3392 protects itself against $V_{out}$ to $+V_S$ hard shorts as well as any over current conditions by reducing the magnitude of output current ($I_O$) to that of the short circuit current limit value ($I_{SC}$). When the output current monitored by Q3 tries to exceed $I_{SC}$, the Current Limit circuit lowers the gate voltage of Q2, lowering the base of Q4, causing the load current through Q4 to diminish. Simultaneously, when the load current exceeds $I_{SC}$, Q5 will turn ON reporting a fault condition. If the output current is allowed to remain excessively high for the degree of heatsinking incorporated, and the junction temperature of the device is allowed to heat beyond 150°C, the Thermal Shutdown circuit will activate and the output will thermally PWM. Again, these modes of operation are safety features of the MC3392 and are not destructive.

### Overvoltage Detect

This circuitry protects the MC3392 from $V_{out}$ voltages in excess of 16 V by lowering the output current to a nondestructive value. With increasing $V_{out}$ voltage (16 V < $V_{out}$ < 45 V) the load current is reduced to below that of $I_{SC}$ and produces a fold back current effect. As $V_{out}$ increases in excess of 16 V, the output current decreases linearly until $V_{out}$ exceeds 45 V. With an infinite heatsink and $V_{out}$ > 45 V, $I_O$ will be less than 100 mA. For the other extreme, no heatsink and $V_{out}$ > 45 V, $I_O$ can be expected to be less than about 400 mA. This behavior of $I_O$ in relation to $V_{out}$ is shown in Figure 13.

For the infinite heatsink case, the output current initially increases with increased voltage until $V_{out}$ exceeds 16 V, thereafter the behavior is expressed as,

$$I_O = I_{SC}\,[1-(V_{out}-16\text{ V})\,/\,30\text{ V}]$$

Beyond 45 V, $I_O$ is limited to less than 100 mA. Anytime the Overvoltage Detect circuit is activated, the gate of Q5 is pulled low causing Q5 to turn ON to report the fault at the $\overline{\text{Fault}}$ pin.

### Inductive Load Clamp

The MC3392 has an internal inductive load clamp for protection against flyback voltages imposed on the output pin in excess of 70 V. The incorporated zener clamp can quickly dissipate up to 60 milli–Joules of inductive flyback energy. Figure 14 shows the maximum inductive load versus load current that the clamp can handle safely. As an example (using Figure 14), if operating the MC3392 to drive a 0.33 H inductor, the maximum load current should be adjusted to 600 mA or less. If the load current is too high for the inductor used, some series resistance can be added to the load to limit the current. If this is not possible, an external clamp must be used to facilitate handling the higher energy. When using an external clamp, the external clamp voltage must be less than 60 V so as to override the internal clamp. The output clamp offers protection for the output when the MC3392 is in the OFF state. During the ON state, other protection features (Overvoltage, Current, and Temperature) are available to protect the output.

### $\overline{\text{Fault}}$ Logic

The $\overline{\text{Fault}}$ is comprised of an internal open drain FET requiring an external pull–up resistor. Typically, a 5.0 k pull–up resistor to a +5.0 V supply is satisfactory. The $\overline{\text{Fault}}$ pin is afforded a minimum of 2000 V ESD protection (Human Body Model) by virtue of the 7.2 V zener diode. The $\overline{\text{Fault}}$ will report a fault (logic low state) whenever the MC3392 experiences a fault condition. Conditions producing a fault are: $I_O$ > 1.3 A (over current/shorted load); $T_J$ > 150°C (over temperature); and $V_{out}$ > 16 V (overvoltage).

If the device goes into Thermal Shutdown, caused by environmental overheating (not resulting from another fault condition), the $\overline{\text{Fault}}$ and $V_{out}$ will thermally PWM as the MC3392 repeatedly heats to shut off, cools, and again turns on. If a current limit fault causes the device to go into Thermal Shutdown, the output will oscillate while the $\overline{\text{Fault}}$ remains pulled low. There is no thermal hysteresis designed in to control the PWM effect and this fault mode of operation is not destructive.

### Fast Turn–Off

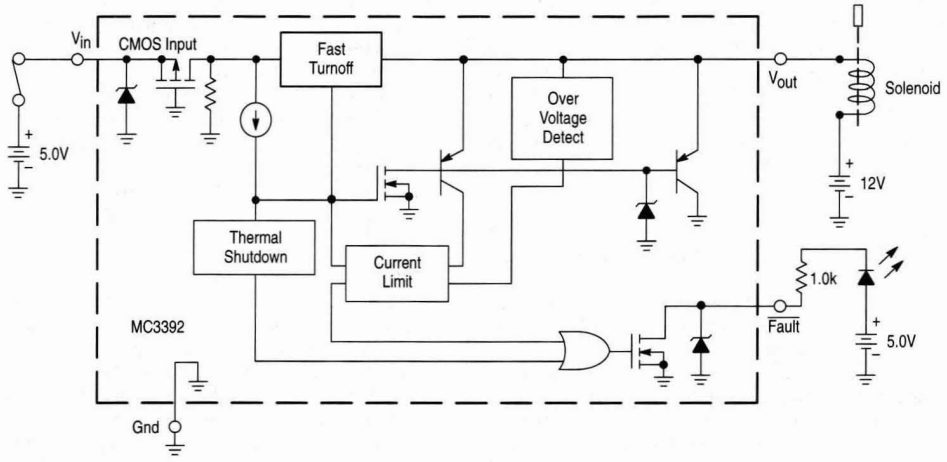
This circuitry enhances the MC3392 turn–off performance. Whenever $V_{in}$ goes to a logic low state, $V_{out}$ is held in an OFF state for approximately 15 µs. During fast turn–off, less than 30 mA of current is allowed to flow producing an abrupt turn–off. This turn–off characteristic can be seen in Figure 12, a photograph of the typical turn–off waveform.

## APPLICATIONS INFORMATION

### Solenoid Driver

The MC3392 can be used to drive a variety of solenoid applications similar to that of Figure 15. For example; driving a solenoid having an inductance of 73.8 mH and a resistance of 95 Ω from a 12 V supply will cause 240 mA of sink current to flow with the MC3392 in the ON state. The resulting current value is within the normal load current operating region and will not produce a fault. Load current is paramount in any design using the MC3392 and must be less than $I_{SC}$ for acceptable operation. If the load current is greater than $I_{SC}$, a current limit fault state will exist. Operation in this state is not destructive as the device will turn off if the Junction Temperature ($T_J$) rises above 150°C. When the Junction Temperature cools below 150°C the device will again turn–on, with a repeat of the cycle. Careful design to acceptable load current limits should be insured for satisfactory operation of an application.

**Figure 15. Solenoid Driver**

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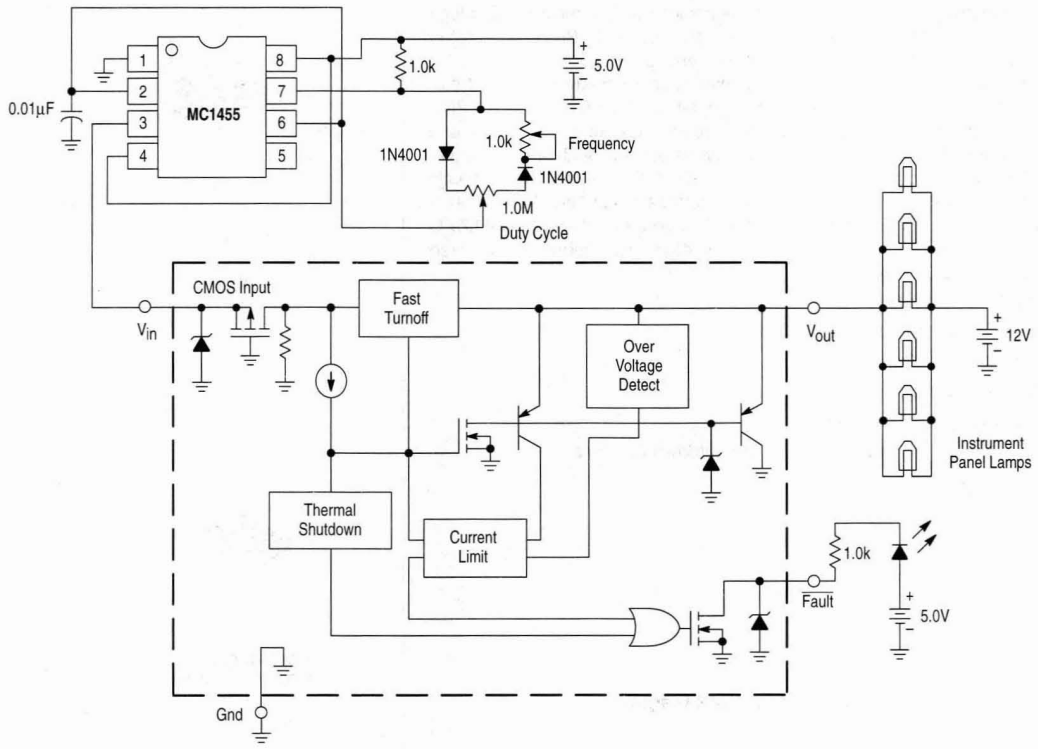
**Instrument Panel Lamp Dimmer Control**

The MC3392 can be used to control the dimming function associated with instrument panel lamps. The brightness of incandescent lamps can be varied by pulse width modulating the input of the MC3392. The modulating signal for the MC3392 can be obtained directly from a microprocessor or, as in Figure 16, from an MC1455 timer. The MC1455 timer is configured as a free–running clock having both frequency and duty cycle control. The typical timer frequency is approximately 80 Hz when the frequency potentiometer is adjusted to 1.0 k. This frequency was chosen so as to avoid any perceptible lamp flicker. The duty cycle potentiometer controls the duty cycle over a range of approximately 3.0% to 97%; When at 3.0% duty cycle, the lamps are essentially off; When at 97% duty cycle, the lamps are essentially full lit. Six incandescent lamps are shown in this application drawing 720 mA total current. Similar applications can be used to drive a variety of lamp loads. The total load current is the primary factor of consideration when driving lamp loads. The total value of $I_O$ must be less than $I_{SC}$.

Another convenient aspect of this application is the LED. The LED can be used to denote the existence of a system fault (overvoltage, current limiting, or thermal shutdown).

**Figure 16. Instrument Panel Lamp Dimmer Control**



MOTOROLA

# MC3399

## Automotive Half-Amp High-Side Switch

**AUTOMOTIVE HALF–AMP HIGH–SIDE SWITCH**

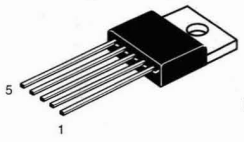
**SEMICONDUCTOR TECHNICAL DATA**

The MC3399 is a High–Side Switch designed to drive loads from the positive side of the power supply. The output is controlled by a TTL compatible input Enable pin. In the "on" state, the device exhibits very low saturation voltages for load currents in excess of 750 mA. The device isolates the load from positive or negative going high voltage transients by abruptly "opening" thus protecting the load from the transient voltage for the duration of the transient. The device automatically re–establishes its original operating state following the transient condition.

The MC3399 is fabricated on a power BIMOS process which combines the best features of Bipolar and MOS technologies. The mixed technology provides higher gain PNP output devices and results in Power Integrated Circuits having substantially reduced quiescent currents.

The device operates over a wide power supply voltage range and can withstand voltage transients (positive or negative) of ±100 V. A rugged PNP output stage along with active clamp circuitry, output current limit and thermal shutdown permit the driving of all types of loads, including inductive. The MC3399 is offered in 5–lead TO–220 and 16–lead SOIC plastic packages to facilitate either "thru–hole" or surface mount use. In addition, it is specified over a wide ambient operating temperature of –40°C to +125°C and is ideally suited for industrial and automotive applications where harsh environments exist.

- Low Switch Voltage Drop
- Load Currents in Excess of 750 mA
- Low Quiescent Current
- Transient Protection Up to ± 100 V
- TTL Compatible Enable Input
- On–Chip Current Limit and Thermal Shutdown Circuitry




Pin 1. Ignition
2. Output
3. Output
4. Ground
5. Input

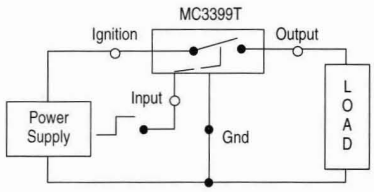
**T SUFFIX**
PLASTIC PACKAGE
CASE 314D

Pins 2 and 3 connected to package tab.

Pin 1. Ignition
2. N.C.
3. N.C.
4. N.C.
5. Ground
6. N.C.
7. Input
8. N.C.
9. Output
10. Output
11. Output
12. Output
13. Output
14. Output
15. Output
16. Output

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751G
SOP(8+8)L

**Representative Block Diagram**




This device contains 52 active transistors.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3399DW | $T_A$ = – 40° to +125°C | SOP(8+8)L |
| MC3399T | | Plastic Power |

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**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Ignition Input Voltage (Continuous)<br>Forward<br>Reverse | $V_{IGN}$ | <br>25<br>–16 | Vdc |
| Ignition Input Voltage (Transient) | $V_{IGN}$ | <br>±60<br>±100 | V |
| Input Voltage | $V_{in}$ | –0.3 to +7.0 | V |
| Output Current | $I_O$ | Internally Limited | A |
| Thermal Resistance<br>Plastic Power Package (Case 314D)<br>Junction–to–Ambient<br>Junction–to–Tab<br>SOP(8+8)L Plastic Package (Case 751G)<br>Junction–to–Ambient<br>Junction–to–Lead 12 | <br><br>$R_{\theta JA1}$<br>$R_{\theta JT}$<br><br>$R_{\theta JA2}$<br>$R_{\theta JL}$ | <br><br>65<br>5.0<br><br>138<br>52 | °C/W |
| Soldering Temperature (for 10 Seconds) | $T_{solder}$ | 260 | °C |
| Junction Temperature | $T_J$ | –40 to +150 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{IGN}$ = 12 V, $I_L$ = 150 mA, –40°C ≤ $T_A$ = +125°C, V Input = "1", unless otherwise noted.)(1)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Operating Voltage | $V_{IGN(min)}$ | 4.5 | – | – | V |
| Switch Voltage Drop (Saturation)<br>$V_{IGN}$ = 4.5 V $I_O$ = 150 mA, $T_A$ = 25°C<br>$I_O$ = 200 mA, $T_A$ = –40°C<br>$I_O$ = 125 mA, $T_A$ = 125°C<br>$V_{IGN}$ = 12 V $I_O$ = 425 mA, $T_A$ = 25°C<br>$I_O$ = 550 mA, $T_A$ = –40°C<br>$V_{IGN}$ = 16 V $I_O$ = 375 mA, $T_A$ = 125°C | $V_{IGN}–V_O$ | <br>–<br>–<br>–<br>–<br>–<br>– | <br>0.2<br>0.3<br>0.3<br>0.3<br>0.3<br>0.4 | <br>0.5<br>0.5<br>0.5<br>0.7<br>0.7<br>0.7 | V |
| Quiescent Current<br>$V_{IGN}$ = 12 V $I_O$ = 150 mA, $T_A$ = 25°C<br>$I_O$ = 550 mA, $T_A$ = –40°C<br>$I_O$ = 300 mA, $T_A$ = 125°C | $I_{GND}$ | <br>–<br>–<br>– | <br>12<br>25<br>10 | <br>50<br>100<br>50 | mA |
| Output Current Limit ($V_O$ = 0 V) | $I_{SC}$ | – | 1.6 | 2.5 | A |
| Output Leakage Current ($V_{IGN}$ = 12 V, Input = "0") | $I_{Leak}$ | – | 10 | 150 | µA |
| Input Voltage<br>High Logic State<br>Low Logic State | <br>$V_{IH}$<br>$V_{IL}$ | <br>2.0<br>– | <br>–<br>– | –<br><br>0.8 | V |
| Input Current<br>High Logic State ($V_{IH}$ = 5.5 V)<br>Low Logic State ($V_{IL}$ = 0.4 V) | <br>$I_{IH}$<br>$I_{IL}$ | <br>–<br>– | <br>120<br>20 | <br>–<br>– | µA |
| Output Turn–On Delay Time<br>Input = "0" → "1", $T_A$ = +25°C (Figures 1 and 3) | $t_{DLY(on)}$ | – | 50 | – | µs |
| Output Turn–Off Delay Time<br>Input = "1" → "0", $T_A$ = +25°C (Figures 1 and 3) | $t_{DLY(off)}$ | – | 5.0 | – | µs |
| Overvoltage Shutdown Threshold | $V_{in(OV)}$ | 26 | 31 | 36 | V |
| Output Turn–Off Delay Time ($T_A$ = + 25°C) to Overvoltage Condition,<br>$V_{in}$ stepped from 12 V to 40 V, V ≤ 0.9 $V_O$ (Figures 1 and 3) | $t_{DLY}$ | – | 2.0 | – | µs |
| Output Recovery Delay Time ($T_A$ = + 25°C)<br>$V_{IGN}$ stepped from 40 V to 12 V, V ≥ 0.9 $V_O$ (Figures 1 and 3) | $t_{RCVY}$ | – | 5.0 | – | µs |

**NOTES:** 1. Typical values represent characteristics of operation at $T_A$ = 25°C.

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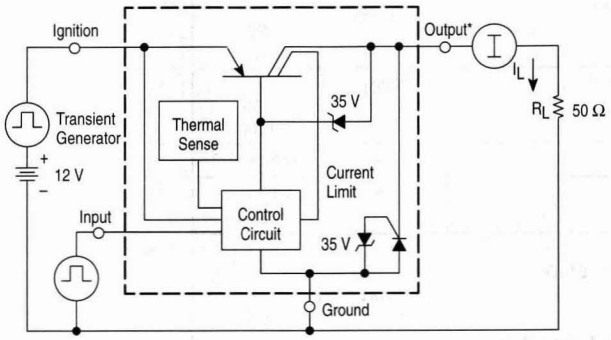
**Figure 1. Transient Response Test Circuit**




**NOTE:** * Depending on load current and transient duration, an output capacitor ($C_O$) of sufficient value may be used to hold up output voltage during the transient, and absorb turn–off delay voltage overshoot.

**Figure 2. Timing Diagram**

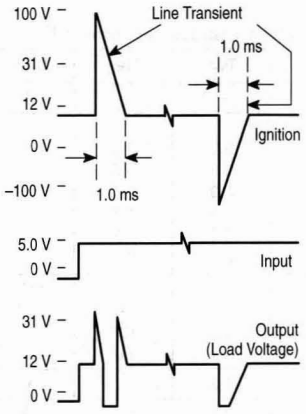



**Figure 3. Response Time Diagram**

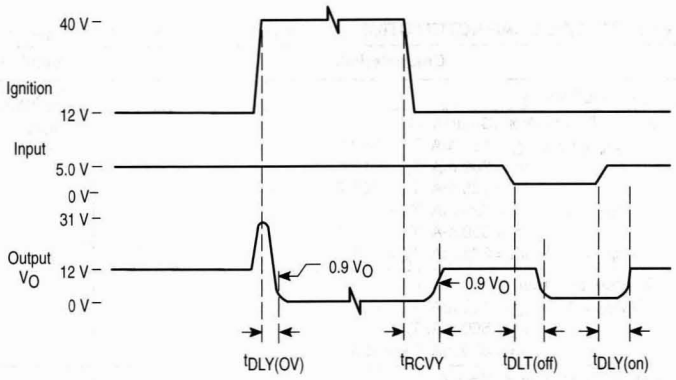



**Figure 4. Switch Voltage Drop versus Load Current**

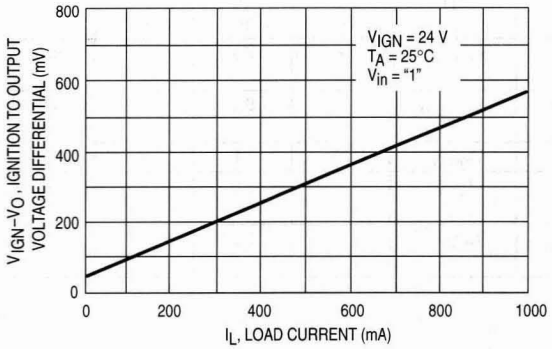
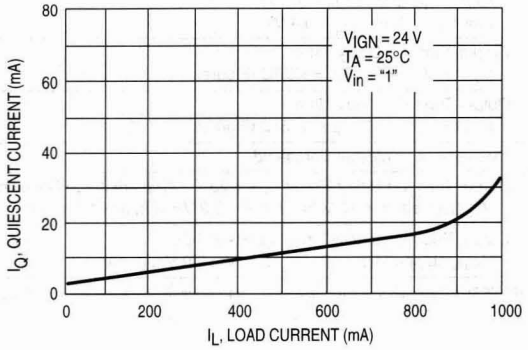



**Figure 5. Quiescent Current versus Load Current**



MOTOROLA

# MC33091A

# High-Side TMOS Driver

**HIGH–SIDE TMOS DRIVER**

**SEMICONDUCTOR TECHNICAL DATA**

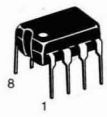
The MC33091A is a High–Side TMOS Driver designed for use in harsh automotive switching applications requiring the capability of handling high voltages attributed to load and field dump transients, as well as reverse and double battery conditions. Few external components are required to drive a wide variety of N–Channel TMOS devices. The MC33091A, driving an appropriate TMOS device, offers economical system solutions for high–side switching large currents. The MC33091A has CMOS compatible input control, charge pump to drive the TMOS power transistor, basic fault detection circuit, $V_{DS}$ monitoring circuit used to detect a shorted TMOS load, and overcurrent protection timer with associated current squaring circuitry.

Short circuit protection is made possible by having a unique $V_{DS}$ voltage to current converter drive an externally programmable integrator circuit. This circuit affords fast detection of a shorted load while allowing difficult loads, such as lamps having high in–rush currents, additional time to turn on.

The $\overline{\text{Fault}}$ output is comprised of an open collector NPN transistor requiring a single pull–up resistor for operation. A fault is reported whenever the MOSFET on–current exceeds an externally programmed set level.

The MC33091A is available in the plastic 8–Pin DIP package as well as the plastic 8–Pin surface mount package.

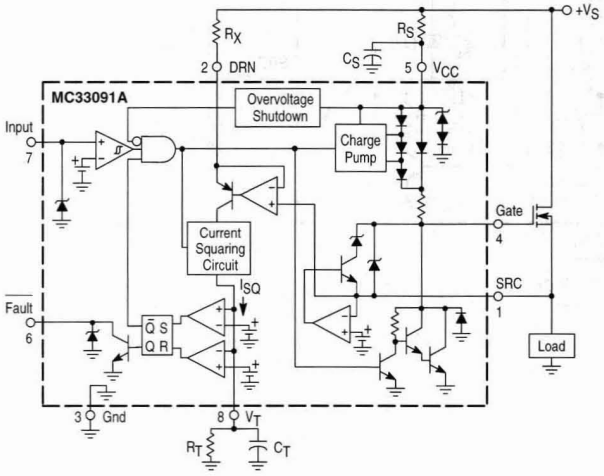
- Designed for Automotive High–Side Driver Applications
- Works with a Wide Variety of N–Channel Power MOSFETs
- Drives Inductive Loads with No External Clamp Circuitry Required
- CMOS Logic Compatible Input Control
- On–Board Charge Pump with No External Components Required
- Shorted Load Detection and Protection
- Forward Overvoltage and Reverse Battery Protection
- Load and Field Dump Protection
- Extended Operating Temperature Range
- $\overline{\text{Fault}}$ Output to Report a MOSFET Overcurrent Condition




**P SUFFIX**
PLASTIC PACKAGE
CASE 626

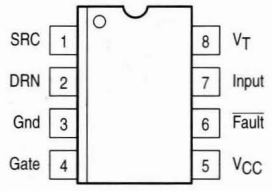
**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**Simplified Block Diagram**




This device contains 54 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33091AD | $T_A$ = – 40° to +125°C | SO–8 |
| MC33091AP | | Plastic DIP |

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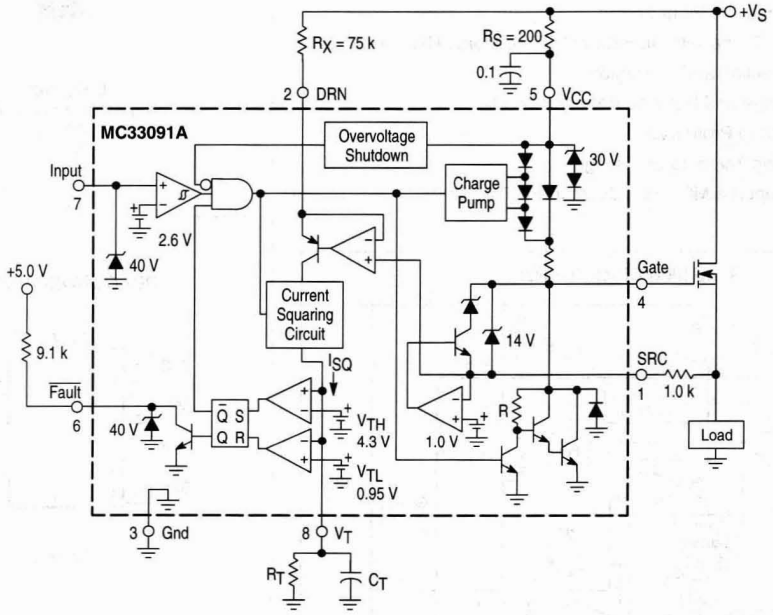
**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage (Pin 5) (Note 1)<br>Continuous (Without Activating Clamp) | $V_{CC}$ | –0.7 to 28<br>7.0 to 28 | V |
| Continuous Supply Clamp Current (Pin 5)<br>DIP Package (Case 626)<br>SO–8 Package (Case 751) | $I_C$ | <br>10<br>1.0 | mA |
| Input Control Voltage Range (Pin 7)<br>Continuous | $V_{in}$ | <br>–0.7 to 28 | V |
| $\overline{\text{Fault}}$ Pull–Up Voltage Range (Pin 6)<br>Continuous | $V_{out}$ | <br>–0.7 to 28 | V |
| Minimum ESD Voltage Capability (Note 2) | ESD | 2000 | V |
| Operating Junction Temperature | $T_J$ | 150 | °C |
| Storage Temperature | $T_{stg}$ | –65 to +150 | °C |
| Operating Ambient Temperature Range | $T_A$ | –40 to +125 | °C |
| Thermal Resistance, Junction–to–Ambient<br>DIP Package (Case 626)<br>SO–8 Package (Case 751) | $R_{\theta JA}$ | <br>100<br>145 | °C/W |

**NOTES:** 1. An internal zener diode is incorporated to protect the device from overvoltage transients in excess of 30 V.
2. ESD testing performed in accordance with Human Body Model (C = 100 pF, R = 1500 Ω).

**Figure 1. Typical Application**



**ELECTRICAL CHARACTERISTICS** (Values are noted under conditions of 7.0 V ≤ $V_{CC}$ ≤ 24 V, –40°C ≤ $T_A$ ≤ +125°C, unless otherwise noted. Typical values reflect approximate mean at $T_A$ = 25°C at time of device characterization.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Current (Note 1)<br>$V_{in}$ = 0 V<br>$V_{in}$ = 5.0 V ($R_X$ = 100 k) | $I_{CC}$ | <br>–<br>– | <br>160<br>2.5 | <br>300<br>6.0 | <br>µA<br>mA |
| Supply Clamp Voltage (Note 2) | $V_Z$ | 29 | – | 35 | V |
| Gate–to–Source Voltage Range (Pin 4) | $V_{GS}$ | 8.0 | 12 | 15 | V |
| Gate Current (Pin 4)<br>$V_G$ = $V_{CC}$ | $I_G$ | <br>30 | <br>– | <br>400 | µA |
| Gate Saturation Voltage ($I_G$ = 10 µA) | $V_{G(sat)}$ | 0 | 1.2 | 1.4 | V |
| Short Circuit Gate Voltage (Note 4) | $I_{GC}$ | 6.4 | 7.0 | 7.7 | V |
| Input Control Threshold Voltage (Pin 7) | <br>$V_{IL}$<br>$V_{IH}$ | <br>–<br>3.5 | <br>2.7<br>2.7 | <br>1.5<br>– | V |
| Input Control Current (Pin 7) ($V_{in}$ = 5.0 V) | $I_{in}$ | – | 100 | 250 | µA |
| Timer Current Constant (Pin 8)<br>($R_X$ = 100 k, $V_T$ = 0, $V_{DS}$ = 1.0 V) (Note 3) | K | <br>0.7 | <br>1.1 | <br>1.5 | $\mu A/V^2$ |
| Timer (Pin 8)<br>Lower Threshold Voltage<br>Upper Threshold Voltage | <br>$V_{TL}$<br>$V_{TH}$ | <br>0.4<br>4.3 | <br>0.95<br>4.6 | <br>1.2<br>5.2 | V |
| $\overline{\text{Fault}}$ Sink Current (Pin 6)<br>$V_F$ = 5.0 V<br>$V_F$ = 0 | <br>$I_{OL}$<br>$I_{OH}$ | <br>500<br>– | <br>–<br>2.0 | <br>–<br>100 | <br>µA<br>nA |
| $\overline{\text{Fault}}$ Saturation Voltage (Pin 6) ($I_F$ = 500 µA) | $V_{OL}$ | – | 0.2 | 0.8 | V |

**NOTES:** 1. The total supply current into Pin 2 and Pin 5 with $R_X$ = 100 k (from Pin 2 to supply) and 45 k pull–up resistor from Pin 6 to supply.
2. An internal zener clamp is provided to protect the device from overvoltage transients on the supply line.
3. The timer current constant is the proportionality constant of the voltage to current converter used to monitor the $V_{DS}$ voltage developed across the FET (from Pin 1 to the supply).
4. The gate voltage will be clamped at approximately 7.0 V above the source voltage whenever the source voltage is less than approximately 1.0 V above ground.

**Figure 2. Supply Current versus Supply Voltage**

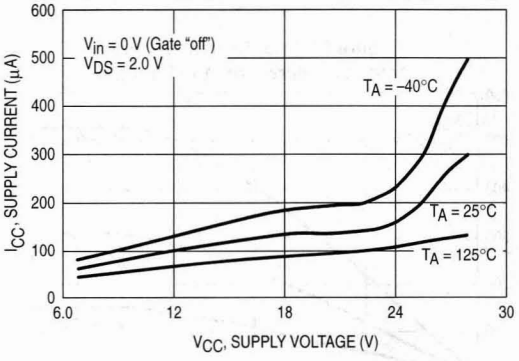



**Figure 3. Operating Current versus Supply Voltage**

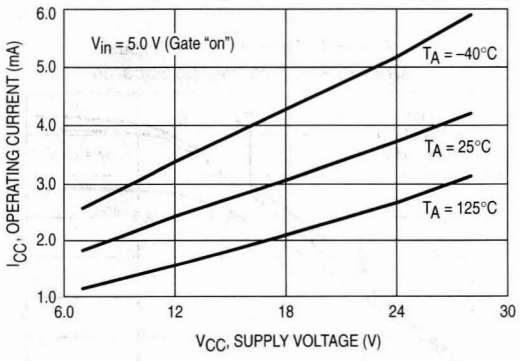



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**Figure 4. Input Control Current versus Input Control Voltage**

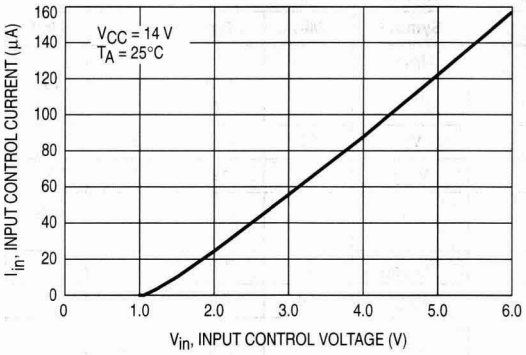


**Figure 5. Input Control Current versus Supply Voltage**

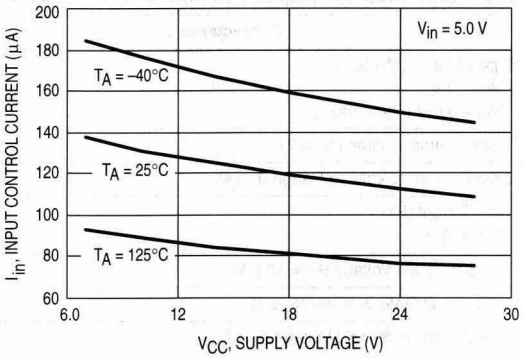


**Figure 6. $\overline{\text{Fault}}$ Voltage versus $\overline{\text{Fault}}$ Sink Current**

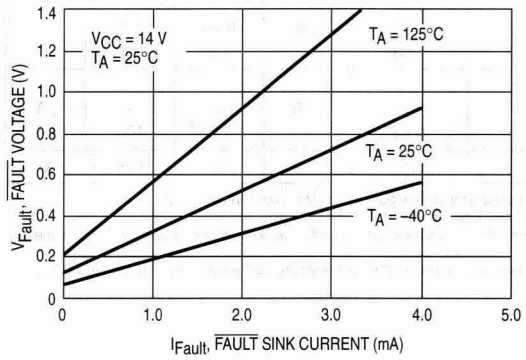


**Figure 7. Squaring Constant "K" versus Supply Voltage**

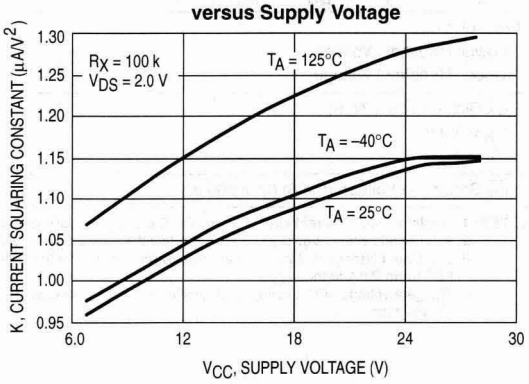


**Figure 8. Timer Current versus Drain–to–Source Voltage Squared**

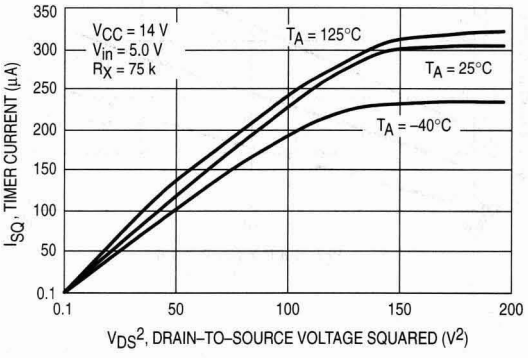


**Figure 9. Timer Current versus Drain–to–Source Voltage Squared**

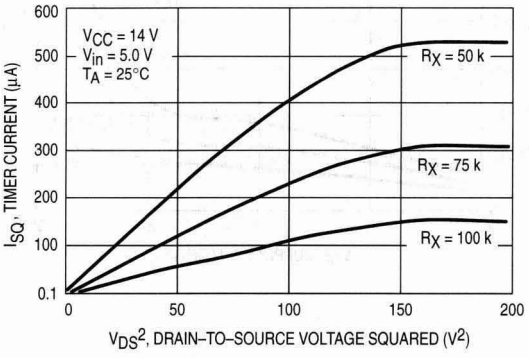


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**Figure 10. Timer Upper Threshold Voltage versus Temperature**

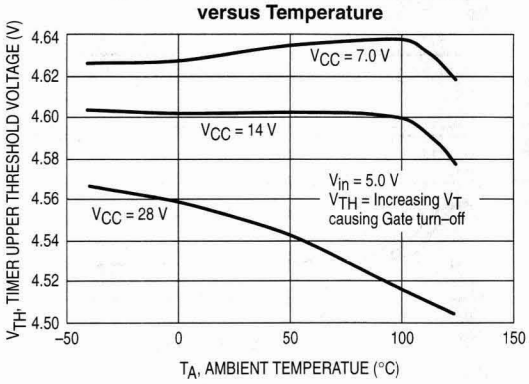


**Figure 11. Timer Upper Threshold Voltage versus Supply Voltage**

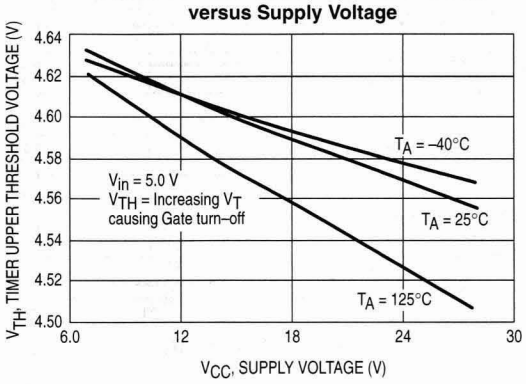


**Figure 12. Timer Lower Threshold Voltage versus Temperature**

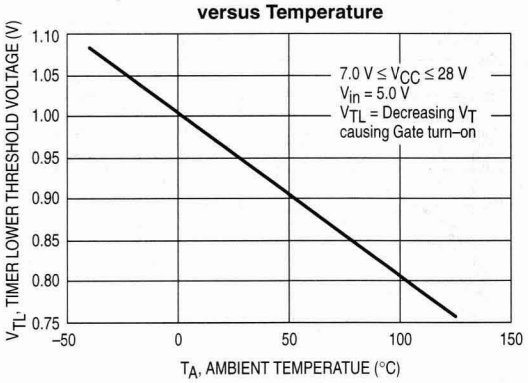


**Figure 13. Timer Lower Threshold Voltage versus Supply Voltage**

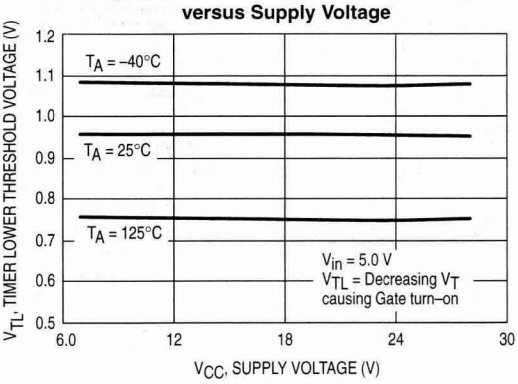


**Figure 14. Gate Voltage versus Input Control Voltage**

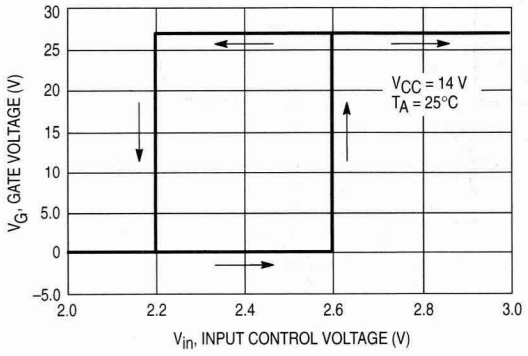


**Figure 15. Gate Voltage versus Supply Voltage**

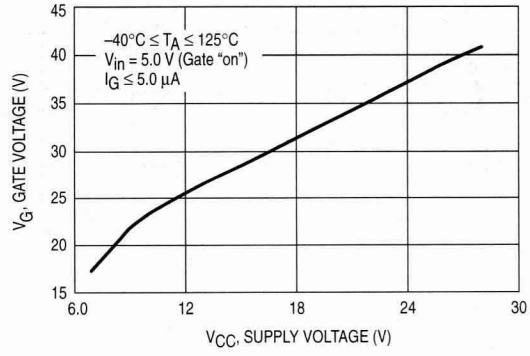


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**Figure 16. Gate Voltage versus Supply Voltage**

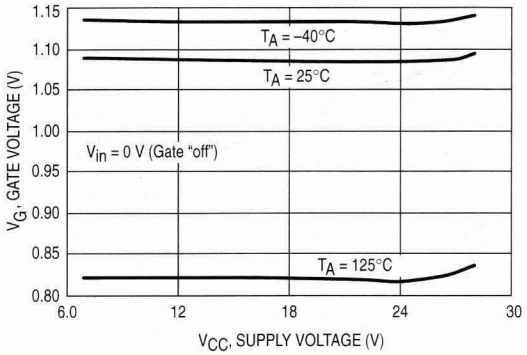


**Figure 17. Gate Voltage verus Gate Current**

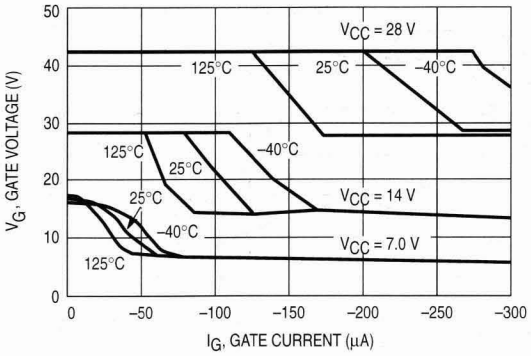


**Figure 18. Gate–to–Source Voltage versus Source Voltage**

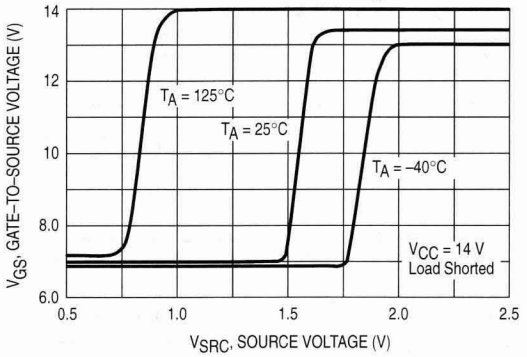


**Figure 19. Gate Current versus Supply Voltage**

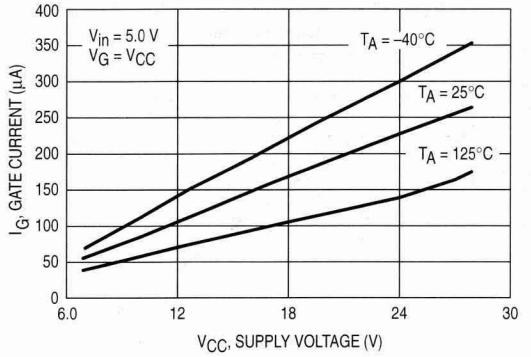


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**Figure 20. Gate Saturation Voltage versus Gate Current**

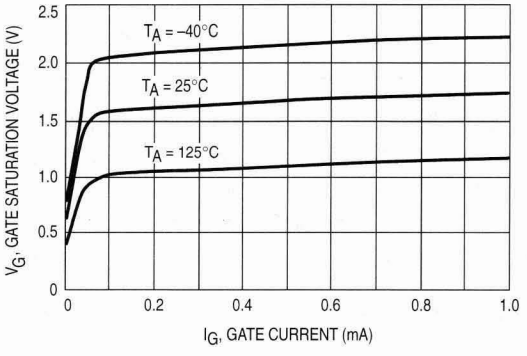


**Figure 21. Gate Saturation Voltage versus Gate Current (Expanded Scale)**

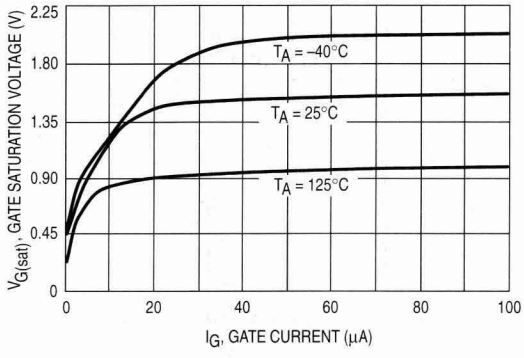

**Figure 22. Drain–to–Source Voltage versus External $R_T$ Timer Resistor**

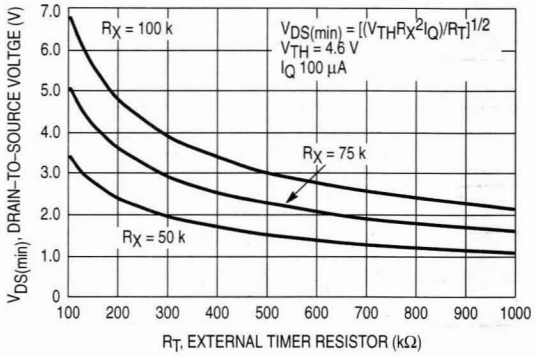


**Figure 23. Timer Response versus $V_{DS(min)}/V_S$ Ratio**

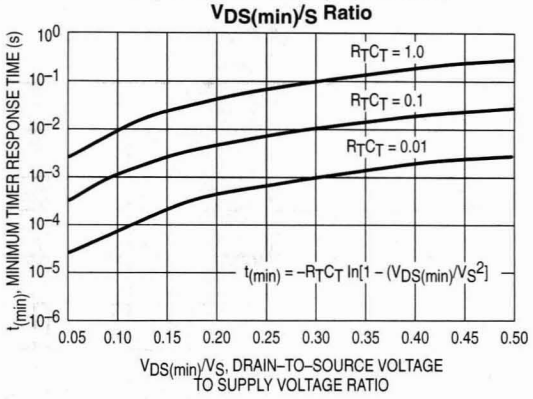
$R_TC_T$ = 1.0
$R_TC_T$ = 0.1
$R_TC_T$ = 0.01
$t_{(min)} = -R_TC_T \ln[1 - (V_{DS(min)}/V_S^2]$
$t_{(min)}$, MINIMUM TIMER RESPONSE TIME (s)
$V_{DS(min)}/V_S$, DRAIN–TO–SOURCE VOLTAGE TO SUPPLY VOLTAGE RATIO

**Figure 24. FET Comparison Gate Response**

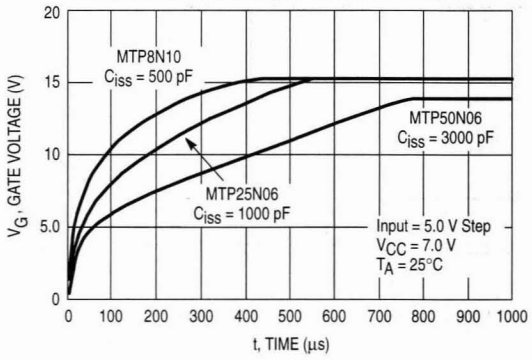


**Figure 25. FET Comparison Gate Response**

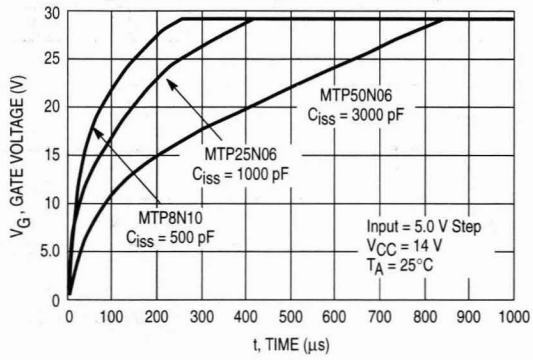


**Figure 26. FET Comparison Gate Response**

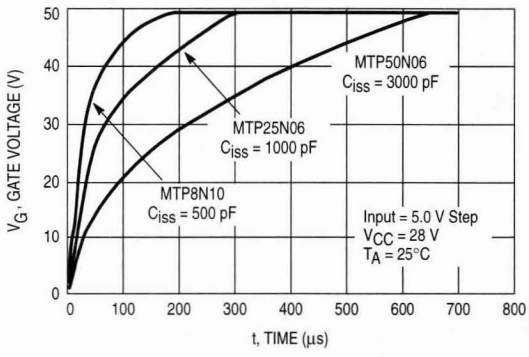


**Figure 27. MTP25N06 Gate Response**

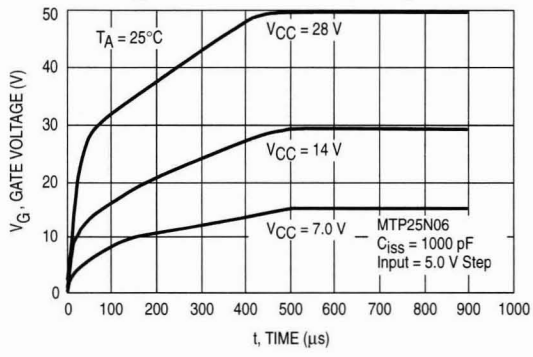


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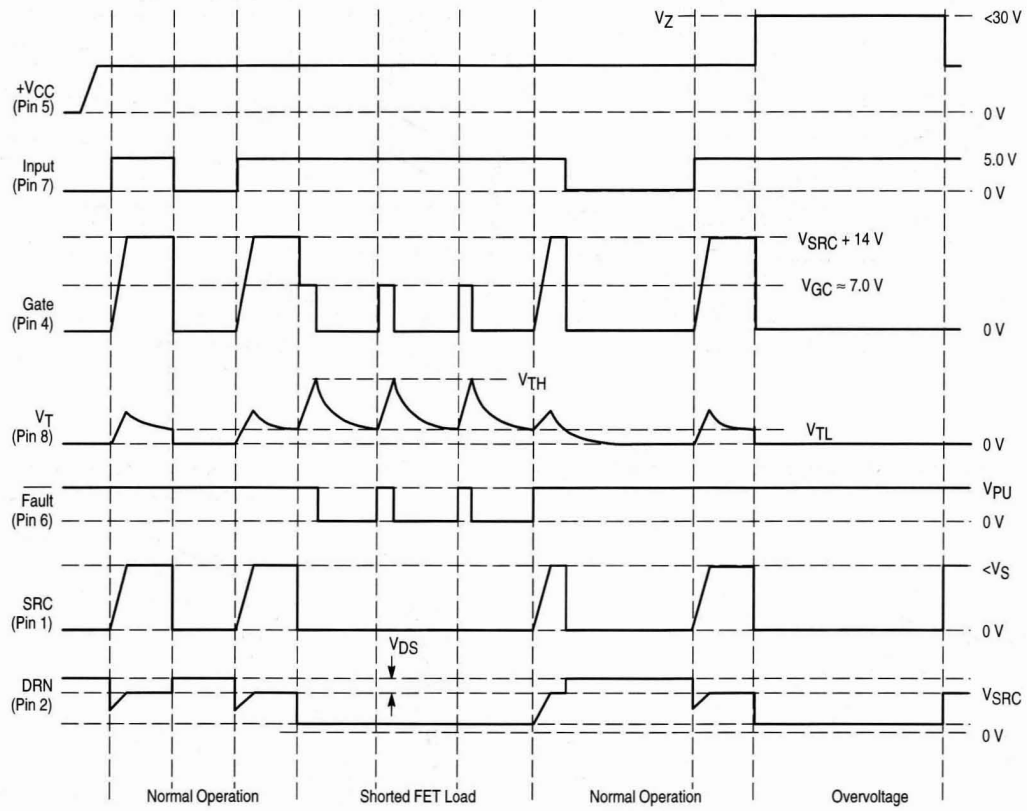
**Figure 28. Descriptive Waveform Diagram**

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## FUNCTIONAL DESCRIPTION

### Introduction

The MC33091A is designed to drive a wide variety of N–channel TMOS transistors in high–side configured, low frequency switching applications. The MC33091A has an internal charge pump to fully enhance the on–state of the TMOS device. The MC33091A protects the TMOS device from shorts to ground and provides a $\overline{\text{Fault}}$ output to report the presence of an overcurrent condition. The few additional external components required allow tailoring of the application's protection level. The protection scheme of the MC33091A uses an externally programmable, nonlinear timer that disables the TMOS device in the event the drain to source voltage exceeds a specified value for a specified duration. Both the value and duration are externally programmable allowing for flexibility in applications.

### Description of Pins

Figure 1 shows a typical application as well as the internal functional blocks of the MC33091A. The discussion to follow references this figure.

**Input (Pin 7):** The logic levels of the Input are compatible with CMOS logic families. The Input enables the protection and charge pump circuitry. With the Input in a logic low state the MC33091A draws only leakage current of less than 300 μA and in this condition the associated TMOS device will be in the "off" state. When the Input is in a logic high state, the Gate voltage (Pin 4) rise is limited to a maximum of 14 V above SRC (Pin 1), due to an internal clamp diode being used and the TMOS device is enhanced full on.

**$\overline{\text{Fault}}$ (Pin 6):** The $\overline{\text{Fault}}$ output is comprised of an open collector NPN transistor capable of sinking at least 500 μA when the TMOS gate is disabled due to an overcurrent condition. When the TMOS device experiences an overcurrent condition, the $\overline{\text{Fault}}$ pin is pulled low.

**SRC (Pin 1):** The SRC pin senses the TMOS source voltage and is the input to the $V_{DS}$ buffer used in conjunction with the DRN pin in monitoring the drain to source voltage developed across the TMOS device. The purpose of the 1.0 k resistor connected to this pin is to protect the SRC input from overvoltage as a result of flyback voltage produced when the TMOS device is used to switch large inductive loads. This resistor can be eliminated when switching noninductive loads.

**DRN (Pin 2):** The DRN is used in conjunction with the SRC pin and together constitute a $V_{DS}$ monitor of the TMOS drain to source voltage. Feedback from the SRC pin will maintain a voltage across the resistor, $R_X$, equal to the $V_{DS}$ voltage developed across the TMOS device. The series resistor, $R_X$, connected between the drain of the TMOS device and DRN of the MC33091A is used in conjunction with the feedback buffer and associated PNP transistor to establish a current proportional to the drain to source voltage, $V_{DS}$, of the TMOS device. This proportional current, acted upon by the current squaring circuit of the MC33091A, is an important part of the TMOS protection scheme.

**$V_{CC}$ (Pin 5):** The $V_{CC}$ pin supplies operational power to the MC33091A. An internal 30 V zener clamp connected to this pin provides overvoltage protection of the MC33091A. When the zener is activated, the MC33091A disables the TMOS device only for the duration of the overvoltage but the $\overline{\text{Fault}}$ output (Pin 6) does not change logic states. The $\overline{\text{Fault}}$ pin does not go to a logic low state during the overvoltage duration since this is not an MC33091A device fault, but an external system fault.

**Gate (Pin 4):** The Gate pin of the MC33091A is the output of the internal charge pump which controls the TMOS device. The charge pump is a voltage tripler and requires no additional external components for operation. When the Input is at a logic low state, the charge pump will be turned off. When the Input is pulled to a logic high state, with no load fault existing, the charge pump turns on and pumps the TMOS gate voltage to at least 8.0 V, typically 10 to 14 V, above $V_{CC}$. An internal zener clamp is incorporated to limit the Gate to approximately 14 V above the source and prevent rupture of the TMOS gate.

**$V_T$ (Pin 8):** The Timer pin ($V_T$) is both an input to the timer window comparators and an output of the current squaring circuit. An external resistor ($R_T$) and capacitor ($C_T$) are tied to this node so as to afford programing the characteristics necessary for protection of the TMOS device.

### Overcurrent Protection Timer

The MC33091A protection scheme is based on the ability of the MC33091A to constantly sense the voltage drop developed across the TMOS device. A low voltage drop is indicative of normal TMOS "on" operation while a large voltage drop represents the existence of an overcurrent condition. By monitoring the TMOS drain to source voltage ($V_{DS}$) the MC33091A is able to detect a shorted load and react to disable the TMOS device. The circuit protection scheme is essentially based on a timer whose rate is dependent on the magnitude of $V_{DS}$. If the drain to source voltage is large (i.e. $V_{DS} = V_{CC}$), the timer will disable the gate drive very quickly. If $V_{DS}$ is only slightly above the normal operating level, the timer will take much longer to disable the gate drive.

Since the power dissipated in the TMOS device is proportional to $V_{DS}^2$, low $V_{DS}$ conditions can be tolerated for a longer time than high $V_{DS}$ conditions. To enhance the system application, the timer time–out of the MC33091A is inversely proportional to $V_{DS}^2$. This approach maximizes the TMOS operating range. The timer parameters are completely user programmable through the use of external components affording application usage of a wide variety of TMOS devices. This is intended to model the generation and dissipation of heat within the TMOS device.

The external components $R_X$, $R_T$ and $C_T$ determine the timer characteristics. Once enabled, the MC33091A will source a current, $I_{SQ}$, from the timer pin that is proportional to $V_{DS}^2$ such that:

$$I_{SQ} = KV_{DS}^2 \qquad (1)$$

where: $K = 1/(R_X^2 I_Q)$

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$I_Q$ is an internal current source parameter of the MC33091A that has a nominal value of 100 μA and $R_X$ is the external resistor in series with the drain of the TMOS device that establishes the value of the voltage to current proportionality constant. Since the parallel combination of $R_T$ and $C_T$ appear at the timer pin ($V_T$), the timer pin voltage, $V_T$, can be written as:

$$V_T(t) = I_{SQ}R_T[1-e^{-t/(R_TC_T)}] \quad (2)$$

With the Input (Pin 7) in a logic high state and no overcurrent condition exists, the TMOS device will be in the "on" state. If the TMOS device experiences an overcurrent condition, $I_{SQ}$ flowing through $R_T$ will increase causing $C_T$ to charge up, in turn causing the timer voltage, $V_T$, to exceed the threshold, $V_{TH}$, of the upper comparator. This sets the latch causing the Q output of the latch to go high (and the Q output to go low), causing the TMOS gate and $\overline{\text{Fault}}$ output (Pin 6) to be pulled low, disabling the TMOS device. Both the current squaring circuit ($I_{SQ}$) and the charge pump are disabled whenever the Q output of the latch goes low. Using Equation 2, the fault time response for an overcurrent condition can be written as:

$$t = -R_TC_T \ln(1-V_{TH}/I_{SQ}R_T) \quad (3)$$

Using Equation 1 and substituting for $I_{SQ}$ in Equation 3:

$$t = -R_TC_T \ln[1-(V_{TH}R_X^2I_Q)/(V_{DS}^2R_T)] \quad (4)$$

When the timer current ($I_{SQ}$) is disabled, the attained $V_{TH}$ voltage at Pin 8 decays according to the $R_TC_T$ time constant until the $V_{TL}$ threshold of the lower comparator is reached. At this point the latch is reset and the TMOS gate, charge pump and the current squaring circuit are again enabled, again turning on the TMOS device. The MC33091A will repeatedly duty cycle the TMOS gate in this manner so long as the overcurrent condition exists and the input control signal remains in a high logic state. The $\overline{\text{Fault}}$ output (Pin 6) will likewise duty cycle.

Consider the case where in Equation 4 the term $(V_{TH}R_X^2I_Q) / (V_{DS}^2R_T) \geq 1$ such that the time period is undefined. Solving for $V_{DS}$ for this case yields the *minimum* drain to source voltage necessary which will *not* allow $V_T$ to charge to the $V_{TH}$ threshold of the upper comparator. In other words, whenever the TMOS on–time period is infinite, *no* TMOS overcurrent condition exists. The minimum drain to source voltage required for uninterrupted continuous TMOS operation is:

$$V_{DS(min)} = [(V_{TH}R_X^2I_Q)/R_T]^{1/2} = (V_{TH}/KR_T)^{1/2} \quad (5)$$

Under *normal* operating steady state TMOS "on" conditions; the values chosen for $R_X$ and $R_T$ should be such that the upper comparator threshold voltage is *never* reached. This insures the TMOS device will always be in operation so long as the $V_{DS(min)}$ is not exceeded.

The minimum time required for the capacitor $C_T$ to charge up to upper comparator threshold voltage occurs when the TMOS device experiences maximum current ($I_{max}$). This will occur when the load, and in turn the source, are shorted to ground resulting in the full battery voltage ($V_S$) to appear directly across the TMOS device. This condition causes maximum $I_{SQ}$ current to be produced by the current squaring circuit. The maximum $I_{SQ}$ current experienced is:

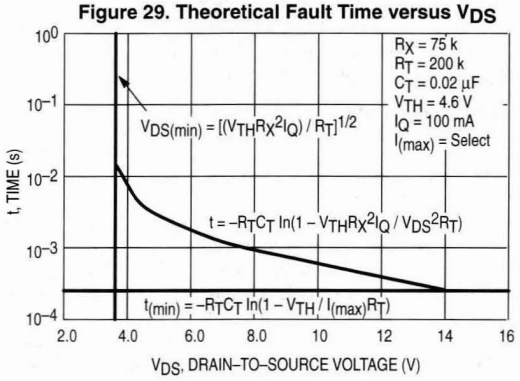
$$I_{SQ(max)} = KV_S^2 = (V_S/R_X)^2/I_Q \quad (6)$$

An expression for the minimum time–out is obtained by substituting $I_Q$ of Equation 6 into Equation 3:

$$t_{(min)} = -R_TC_T \ln[1-V_{TH}/(I_{SQ(max)}R_T)] \quad (7)$$

Equation 4 is shown graphically along with the asymptotic limits imposed by Equations 5 and 7 in Figure 29.

**Figure 29. Theoretical Fault Time versus $V_{DS}$**




When driving incandescent lamp loads, the minimum timer time–out (time required for the $V_T$ voltage to reach $V_{TH}$ threshold of the upper comparator) should be set long enough so as to *not* allow the in–rush current of incandescent lamp to cause a false trigger, yet short enough to afford the TMOS device survival protection against direct shorts under worst case supply and temperature conditions.

### TMOS Driver Power Dissipation

Under load short conditions, the MC33091A will duty cycle the TMOS gate. The power dissipation in this mode can be significant. For this reason proper heatsinking of the TMOS device is essential as is the selection of compatible external components so as to protect the TMOS device from destruction. In most cases, the heatsink required to handle the TMOS power dissipation under normal operating conditions will be adequate to insure the device survives a short circuit for an indefinite time under worst case conditions.

The MC33091A can protect the TMOS device under a direct load short condition. If the source voltage is less than about 1.5 V above ground, which will normally be the case in the event of a dead short, the MC33091A will clamp the gate to source voltage at 7.0 V. This action will limit the TMOS current and power dissipated under a direct load short condition.

The data sheet for the particular TMOS device being used will normally reveal the current value, $I_{DS(max)}$, to be expected under a dead short condition. TMOS data sheets normally depict graphs of drain current versus drain to source voltage for various gate to source voltages from which the drain current at 7.0 V $V_{GS}$, $I_{DS(max)}$, can reasonably be approximated. Using this information, the peak TMOS power dissipation under a dead short condition is approximated to be:

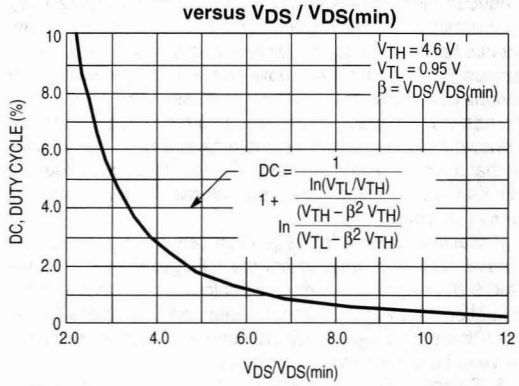
$$P_{D(peak)} = V_{S(max)}I_{DS(max)} \quad (8)$$

The average power is equal to the peak power dissipation multiplied by the duty cycle (DC):

$$P_{D(avg)} = P_{D(peak)}DC \quad (9)$$

As long as the average power, in Equation 9, is less than the maximum power dissipation of the TMOS device under normal conditions, the short circuit protection scheme of the MC33091A will adequately protect the TMOS device. The duty cycle at which the MC33091A controls the gate can be determined by using Figure 30.

**Figure 30. MC33091A Duty Cycle versus $V_{DS}$ / $V_{DS(min)}$**




As previously discussed, $I_{SQ}$ is externally dependant on the sensed $V_{DS}$ voltage developed across the TMOS device and $R_X$ in accordance with Equations 1 and 2. At the onset of an overload condition, the voltage across $C_T$ will be less than the $V_{TH}$ threshold voltage of the upper comparator with the TMOS device in an "on" state. $I_{SQ}$ current will increase dramatically and the timing capacitor $C_T$ charges toward $V_{TH}$. When the voltage on $C_T$ reaches the $V_{TH}$ threshold voltage of the upper comparator, the upper comparator output goes high setting the latch output (Q) high, turning on the open collector NPN transistor and pulling the $\overline{\text{Fault}}$ output low. At the same time, $I_{SQ}$ is switched off, allowing $C_T$ to discharge through resistor $R_T$ to $V_{TL}$, at which time the TMOS device is again switched on. This action is repeated so long as the overload condition exists. The $V_{TL}$ and $V_{TH}$ thresholds are internally set to approximately 0.95 V and 4.6 V respectively.

The charge time ($t_c$) of $C_T$ can be shown as:

$$t_c = -R_T C_T \ln[1-(V_{TH}-V_{TL})/(I_{SQ}R_T-V_{TL})] \quad (10)$$

The discharge time ($t_d$) of $C_T$ can be shown as:

$$t_d = -R_T C_T \ln(V_{TL}/V_{TH}) \quad (11)$$

The duty cycle is defined as charge time divided by the charge plus discharge time and represented by:

$$DC = t_c/(t_c+t_d) \quad (12)$$

Substituting Equations 10 and 11 into 12:

$$DC = 1/1+\ln(V_{TL}/V_{TH})/\ln\{(V_{TH}-\beta^2V_{TH})/(V_{TL}-\beta^2V_{TH})\} \quad (13)$$

where: $\beta = V_{DS}/V_{DS(min)}$

Notice the duty cycle is dependent *only* on the ratio of the drain to source voltage, $V_{DS}$, of the TMOS device to the minimum drain to source voltage, $V_{DS(min)}$, allowing uninterrupted continuous TMOS operation as calculated in Equation 5. A graph of Equation 13 is shown in Figure 30 and is valid for any ratio of $V_{DS}$ to $V_{DS(min)}$. Knowing this ratio, the duty cycle can be determined by using Figure 30 or Equation 13 and knowing the duty cycle, the average power dissipation can be calculated by using Equation 9.

If the TMOS device experiences a hard load short to ground a minimum duty cycle will be experienced which can be calculated. When this condition exists, the TMOS device experiences a $V_{DS}$ voltage of $V_S$ which is sensed by the MC33091A. The MC33091A very rapidly charges the timing capacitor $C_T$ to $V_{TH}$ shutting down the TMOS device. This condition produces the minimum duty cycle for the specific system conditions. The minimum duty cycle can be calculated for any valid $V_S$ voltage by substituting the value of $V_S$ used for $V_{DS}$ in Equation 13 and solving for the duty cycle.

Knowing the duty cycle and peak power allows determination of the average power as was pointed out in Equation 9. TMOS data sheets specify the maximum allowable junction temperature and thermal resistance, junction–to–case, at which the device may be operated. Knowing the average power and the device thermal information, proper heatsinking of the TMOS device can be determined.

The duty cycle graph (Figure 30) reveals lower values of $V_{DS(min)}$ produce shorter duty cycles, for given $V_{DS}$ voltages. The minimum duty cycle, being limited to the case where $V_{DS} = V_S$, increases as higher values of $V_S$ are used.

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## APPLICATION

The following design approach will simplify application of the MC33091A and will insure the components chosen to be optimal for a specific application.

1. Characterize the load impedance and determine the maximum load current possible for the load supply voltage used.

2. Select a TMOS device capable of handling the maximum load current. Though the MC33091A will equally drive our competitors products, it is hoped you will select one of the many TMOS devices listed in Motorola's *Power MOSFET Transistor Data Book*.

3. Determine the maximum steady state $V_{DS}$ voltage the TMOS device will experience under *normal* operating conditions. Typically, this is the maximum load current multiplied by the specified $R_{DS(on)}$ of the TMOS device. Junction temperature considerations should be taken into account for the $R_{DS(on)}$ value since it is significantly temperature dependent. Normally, TMOS data sheets depict the effect of junction temperature on $R_{DS(on)}$ and an $R_{DS(on)}$ value at some considered maximum junction temperature should be used. Various graphs relating to $R_{DS(on)}$ are depicted in Motorola TMOS data sheets. Though Motorola TMOS devices typically specify a maximum allowable junction temperature of 150°C, in a practical sense, the user should strive to keep junction temperature as low as possible so as to enhance the applications long term reliability. The maximum steady state $V_{DS}$ voltage the TMOS device will experience under *normal* operating conditions is thus:

$$V_{DS(norm)} = I_{L(max)}R_{DS(on)} \quad (14)$$

4. Calculate the maximum power dissipation of the TMOS device under *normal* operating conditions:

$$P_{D(max)} = V_{DS(on)}I_{L(max)} \quad (15)$$

5. The calculated maximum power dissipation of the TMOS device dictates the required thermal impedance for the application. Knowing this, the selection of an appropriate heatsink to maintain the junction temperature below the maximum specified by the TMOS manufacture for operation can be made. The required overall thermal impedance is:

$$TR_{JA} = (T_{J(max)} - T_{A(max)})/P_{D(max)} \quad (16)$$

Where $T_{J(max)}$, the maximum allowable junction temperature, is found on the TMOS data sheet and $T_{A(max)}$, the maximum ambient temperature, is dictated by the application itself.

6. The thermal resistance, $TR_{JA}$, represents the maximum overall or total thermal resistance, from junction to the surrounding ambient, allowable to insure the TMOS manufactures maximum junction temperature will not be exceeded. In general, this overall thermal resistance can be considered as being made up of several separate minor thermal resistance interfaces comprised of $TR_{JC}$, $TR_{CS}$ and $TR_{SA}$ such that:

$$TR_{JA} = TR_{JC} + TR_{CS} + TR_{SA} \quad (17)$$

Where $TR_{JC}$, $TR_{CS}$ and $TR_{SA}$ represent the junction–to–case, case–to–heatsink and heatsink–to–ambient thermal resistances respectively. $TR_{CS}$ and $TR_{SA}$ are the only parameters the device user can influence.

The case–to–heatsink thermal resistance, $TR_{CS}$, is material dependent and can be expressed as:

$$TR_{CS} = \rho \times t/A \quad (18)$$

Where "ρ" is the thermal resistivity of the heatsink material (expressed in °C/Watt/Unit Thickness), "t" is the thickness of heatsink material, and "A" is the contact area of the case–to–heatsink. Heatsink manufactures specify the value of $TR_{CS}$ for standard heatsinks. For nonstandard heatsinks, the user is required to calculate $TR_{CS}$ using some form of the basic Equation 18.

The required heatsink–to–ambient thermal resistance, $TR_{SA}$, can easily be calculated once the terms of Equation 17 are known. Substituting $TR_{JA}$ of Equation 16 into Equation 17 and solving for $TR_{SA}$ produces:

$$TR_{SA} = (T_{J(max)}-T_{A(max)})/P_{D(max)}-(TR_{JC}+TR_{CS}) \quad (19)$$

Consulting the heatsink manufactures catalog will provide $TR_{CS}$ information for various heatsinks under various mounting conditions so as to allow easy calculation of $TR_{SA}$ in units of °C/W (or when multiplied by the power dissipation produces the heatsink mounting surface temperature rise). Furthermore, heatsink manufactures typically specify for various heatsinks, heatsink efficiency in the form of mounting surface temperature rise above the ambient conditions for various power dissipation levels. The user should insure that the heatsink selected will provide a surface temperature rise somewhat less than the maximum capability of the heatsink so that the device junction temperature will not be exceeded. The user should consult the heatsink manufacturers catalog for this information.

7. Set the value of $V_{DS(min)}$ to something greater than the *normal operating* drain to source voltage, $V_{DS(norm)}$, the TMOS device will experience as calculated in Step 3 above (Equation 14). From a practical standpoint, a value two or three times $V_{DS(norm)}$ expected under normal operation will prove to be a good starting point for $V_{DS(min)}$.

8. Select a value of $R_T$ less than 1.0 MΩ for minimal timing error whose value is compatible with $R_X$ ($R_X$ will be selected in Step 9 below). A recommended starting value to use for $R_T$ would be 470 k. The consideration here is that the input impedance of the threshold comparators are approximately 10 MΩ and if $R_T$ values greater than 1.0 MΩ are used, significant timing errors may be experienced as a result of input bias current variations of the threshold comparators.

9. Select a value of $R_X$ which is compatible with $R_T$. The value of $R_X$ should be between 50 k and 100 k. Recall in Equation 5 that $V_{DS(min)}$ was determined by the combined selection of $R_X$ and $R_T$. Low values of $R_X$ will give large values for K ($K = 4.0\ \mu A/V^2$ for $R_X = 50$ k) causing $I_{SQ}$ to be very sensitive to $V_{DS}$ variations (see Equation 1). This is desirable if a minimum $V_{DS}$ trip point is needed in the 1.0 V range since small $V_{DS}$ values will generate measurable currents. However, at high $V_{DS}$ values, TMOS device currents become excessively large and the current squaring function begins to deviate slightly from the predicted value due to high level injection effects occurring in the output PNP of the current squaring circuit. These effects can be seen when $I_{SQ}$ exceeds several hundred microamps. See Figure 22 for graphical aid in the selection of $R_T$ and $R_X$.

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10. Calculate the shorted load average power dissipation for the application using Equations 8 and 9. This involves determining the peak shorted load power dissipation of the TMOS device and gate duty cycle. The duty cycle is based on $V_{DS(min)}$, the value of $V_{DS}$ under shorted conditions (i.e. $V_{S(max)}$).

11. The calculated shorted load average power dissipation of Step 10 should be less than the maximum power dissipation under *normal* operating conditions calculated in Step 4. If this is not the case, there are two options.

**Option one** is to reduce the thermal resistance of the TMOS device heatsink, in other words, use a larger or better heatsink. This though, is not always practical to do particularly if restricted by size.

**Option two** is to set $V_{DS(min)}$ to the lowest practical value. If for instance $V_{DS(min)}$ is set to 4.0 V when only 2.0 V are needed, the short circuit duty cycle will be over twice as large, resulting in double the TMOS device power dissipated. Keeping $V_{DS(min)}$ to a minimum, reduces the shorted load average power.

12. Choose a value of $C_T$. The value of $C_T$ can be determined either by trial and error or by characterizing the $V_{DS}$ waveform for the load and selecting a capacitor value that generates a minimum fault time curve (see Equation 4) that encompasses the $V_{DS}$ versus time waveform. The value of $C_T$ has *no* effect on the duty cycle itself as was pointed out earlier. See Figure 23 for a graphical selection of $C_T$.

### Inductive Loads

The TMOS device is turned off by pulling the gate to near ground potential. Turning off an inductive load will cause the source of the TMOS device to go below ground due to flyback voltage to the point where the TMOS device may become biased on again allowing the inductive energy to be dissipated through the load. An internal 14 V zener diode clamp from the gate to source pin limits how far the source pin can be pulled below ground. For high inductive loads, it may be necessary to have an external 10 k current limiting resistor in series with the source pin to limit the clamp current in the event the source pin is pulled more than 14 V below ground.

### Transient Faults

The MC33091A is not able to withstand automotive voltage transients directly. By correctly sizing resistor $R_S$ and capacitor $C_S$, the MC33091A can withstand load dump and other automotive type transients. The $V_{CC}$ voltage is clamped at approximately 30 V through the use of an internal zener diode.

Under reverse battery conditions, the load will be energized in reverse due to the parasitic body diode inherent in the TMOS device. Under this condition, the drain is grounded and the MC33091A clamps the gate at 0.7 V below the battery potential. This turns the TMOS device on in reverse and minimizes the voltage across the TMOS device resulting in minimal power dissipation. Neither the MC33091A nor the TMOS device will be damaged under such a condition. In addition, if the load can tolerate a reverse polarity, the load will not be damaged. Caution; some sensitive applications may not tolerate a reverse polarity load condition with reverse battery polarity.

There is no protection of the TMOS device during a reverse battery condition if the load itself is already shorted to ground. The MC33091A will not incur damage under this specialized reverse battery condition but the TMOS device may be damaged since there could be significant energy available from the battery to be dissipated in the TMOS device.

The MC33091A will withstand a maximum $V_{CC}$ voltage of 28 V and with the proper TMOS device used, the system can withstand a double battery condition.

Figure 36 depicts a method of protecting the FET from positive transient voltages in excess of the rated FET breakdown voltage. The zener voltage, in this case, should be less than the FET breakdown voltage. The diode, D, is necessary where reverse battery protection of the gate of the FET is required.

### EMI Concern

The gate capacitance and thus the size of the TMOS device used will determine the turn–on and turn–off times experienced. In a practical sense, smaller TMOS devices have smaller gate capacitances and give rise to higher slew rates. By way of example, the turn–on of an MPT50N06 TMOS device might be of the order of 80 μs while that of an MPT8N10 might be 10 μs (see Figure 25). The speed of turn–on or turn–off can be calculated by assuming the charge pump to supply approximately 100 μA over the time the gate capacitance will transition a $V_{GS}$ voltage of 0 V to 10 V. In reality, the $V_{GS}$ voltage will be greater than 10 V, but the additional increase in TMOS drain current will be minimal for $V_{GS}$ voltages greater than 10 V.

The charge pump current is sized so that turn–on time need not be of concern in all but the most critical of applications. Where limiting of EMI is of concern, the charge pump of the MC33091A may be slew rate limited by adding an external feedback capacitor from the gate–to–source of the TMOS device for slow down adjustment of both turn–on and turn–off times (see Figure 33). Figures 31 through 35 depict various methods of modifying the turn–on or turn–off times.

Figure 35 depicts a method of using only six external components to decrease turn–off time and clamp the flyback voltage associated with switching inductive loads. $V_{GS(th)}$ used in the critical component selection criteria refers to the gate–to–source threshold voltage of the FET used in the application.

Caution should be exercised when slowing down the switching transition time since doing so can greatly increase the average power dissipation of the TMOS device. The resulting increase in power dissipation should be taken into account when selecting the $R_TC_T$ time constant values in order to protect the TMOS device from any overcurrent condition.

**Figure 31. Slow Down FET Turn–On**

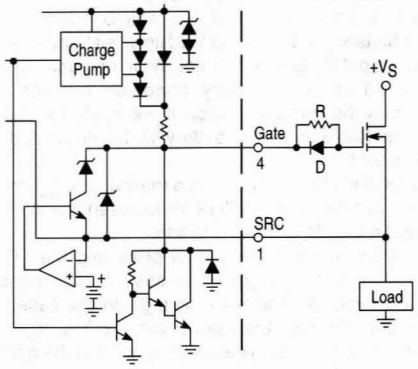



**Figure 32. Slow Down FET Turn–Off**

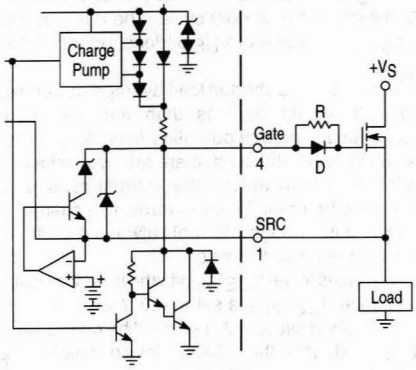



**Figure 33. Slow Down Turn–On and Turn–Off of FET**

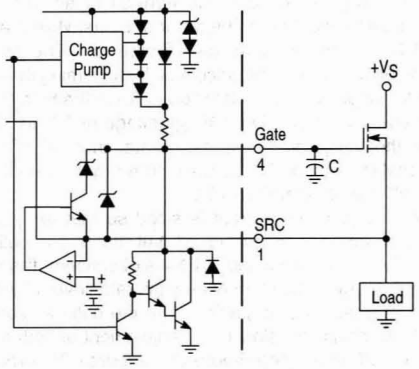



**Figure 34. Independent Slow Down Adjustment of FET Turn–On and Turn–Off**

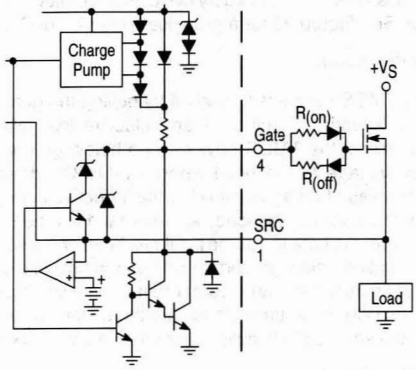



**Figure 35. Decreased FET Turn–Off Time with Inductive Flyback Voltage Clamp**

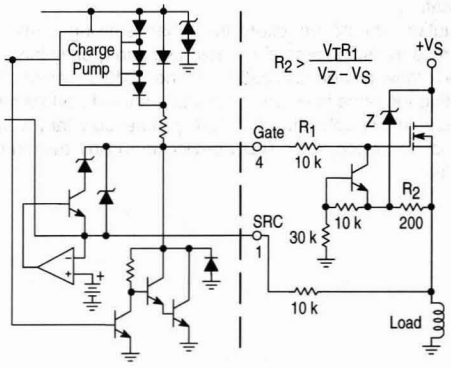
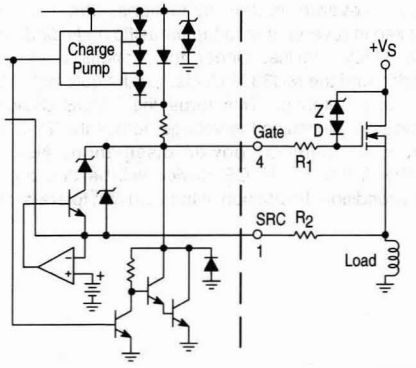



**Figure 36. Overvoltage Protection of FET**



MOTOROLA

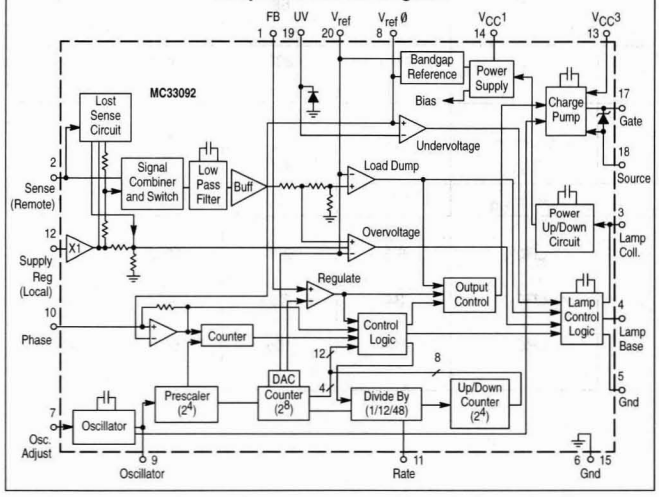
# Alternator Voltage Regulator

The MC33092 is specifically designed for voltage regulation and Load Response Control (LRC) of diode rectified alternator charging systems, as commonly found in automotive applications. The MC33092 provides load response control of the alternator output current to eliminate engine speed hunting and vibration due to sudden electrical loads which cause abrupt torque loading of the engine at low RPM. Two load response rates are selectable using Pin 11. The timing of the response rates is dependent on the oscillator frequency.

In maintaining system voltage, the MC33092 monitors and compares the system battery voltage to an externally programmed set point value and pulse width modulates an N–channel MOSFET transistor to control the average alternator field current.

- Forced Load Response Control (LRC) with Heavy Load Transitions at Low RPM
- Capable of Regulating Voltage to ± 0.1 V @ 25°C
- Operating Frequency Selectable with One External Resistor
- < 0.1 V Variation over Speed Range of 2000 to 10,000 RPM
- < 0.4 V Variation over 10% to 95% of Maximum Alternator Output
- Maintains Regulation with External Loads as Low as 1.0 A
- Load Dump Protection of Lamp, Field Control Devices, and Loads
- Duty Cycle Limit Protection
- Provides High Side MOSFET Control of a Ground Referenced Field Winding
- Controlled MOSFET and Flyback Diode Recovery Characteristics for Minimum RFI
- < 2.0 mA Standby Current from Battery @ 25°C
- < 3.0 mA Standby Current from Battery Over Temperature Range
- Optional 2.5 or 10 sec. LRC Rate Control (Osc. Freq. = 280 kHz)
- Undervoltage, Overvoltage and Phase Fault (Broken Belt) Detection

**Simplified Block Diagram**



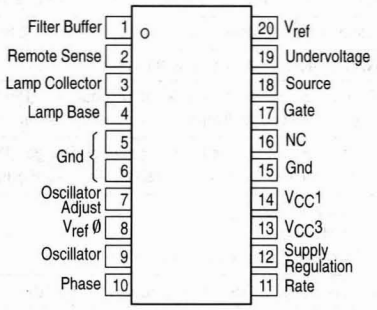

# MC33092

## ALTERNATOR VOLTAGE REGULATOR

**SEMICONDUCTOR TECHNICAL DATA**

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751D
(SO–20L)

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33092DW | $T_A$ = – 40° to +125°C | SO–20L |

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## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage<br>Load Dump Transient Voltage (Note 1)<br>Negative Voltage (Note 2) | $V_{bat}$<br>$+V_{max}$<br>$-V_{min}$ | 24<br>40<br>– 2.5 | V<br>V<br>V |
| Power Dissipation and Thermal Characteristics<br>Maximum Power Dissipation @ $T_A$ = 125°C<br>Thermal Resistance, Junction–to–Ambient | <br>$P_D$<br>$R_{\theta JA}$ | <br>867<br>75 | <br>mW<br>°C/W |
| Operating Junction Temperature | $T_J$ | +150 | °C |
| Operating Ambient Temperature Range | $T_A$ | – 40 to +125 | °C |
| Storage Temperature Range | $T_{stg}$ | – 45 to +150 | °C |

## ELECTRICAL CHARACTERISTICS (External components per Figure 1, $T_A$ = 25°C, unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DC CHARACTERISTICS** | | | | | |
| Regulation Voltage<br>(Determined by external resistor divider) | $V_{Reg}$ | – | 14.85 | – | V |
| Regulation Voltage Temperature Coefficient | $T_C$ | –13 | –11 | – 9.0 | mV/°C |
| Suggested Battery Voltage Operating Range | $V_{bat}$ | 11.5 | 14.85 | 16.5 | V |
| Power Up/Down Threshold Voltage (Pin 3) | $V_{Pwr}$ | 0.5 | 1.2 | 2.0 | V |
| Standby Current,<br>$V_{bat}$ = 12.8 V, Ignition off, $T_A$ = 25°C<br>$V_{bat}$ = 12.8 V, Ignition off, – 40°C≤$T_A$≤125°C | <br>$I_{Q1}$<br>$I_{Q2}$ | <br>–<br>– | <br>1.3<br>– | <br>2.0<br>3.0 | <br>mA<br>mA |
| Zero Temperature Coefficient Reference Voltage, (Pin 8) | $V_{ref}$ Ø | 1.1 | 1.25 | 1.4 | V |
| Band Gap Reference Voltage (Pin 20) | $V_{ref}$ | 1.7 | 2.0 | 2.3 | V |
| Band Gap Reference Temperature Coefficient | TC | –13 | –11 | – 9.0 | mV/°C |
| Sense Loss Threshold (Pin 2) | $S_{Loss(th)}$ | – | 0.6 | 1.0 | V |
| Phase Detection Threshold Voltage (Pin 10) | $P_{Th}$ | 1.0 | 1.25 | 1.5 | V |
| Phase Rotation Detection Frequency (Pin 10) | $P_{Rot}$ | – | 36 | – | Hz |
| Undervoltage Threshold (Pin 19) | $V_{UV}$ | 1.0 | 1.25 | 1.5 | V |
| Overvoltage Threshold (Pin 2, or Pin 12 if Pin 2 is not used) | $V_{OV}$ | 1.09($V_{ref}$) | 1.12($V_{ref}$) | 1.16($V_{ref}$) | V |
| Load Dump Threshold (Pin 2, or Pin 12 if Pin 2 is not used) | $V_{LD}$ | 1.33($V_{ref}$) | 1.4($V_{ref}$) | 1.48($V_{ref}$) | V |
| **SWITCHING CHARACTERISTICS** | | | | | |
| Fundamental Regulation Output Frequency, (Pin 17)<br>(Clock oscillator frequency divided by 4096) | f | – | 68 | – | Hz |
| Suggested Clock Oscillator Frequency Range, (Pin 9)<br>(Determined by external resistor, $R_T$, see Figure 6) | $f_{osc}$ | 205 | 280 | 350 | kHz |
| Duty Cycle (Pin 17)<br>At Start–up<br>During Overvoltage Condition | <br>$Start_{DC}$<br>$OV_{DC}$ | <br>27<br>3.5 | <br>29<br>4.7 | <br>31<br>5.5 | <br>%<br>% |
| Low/High RPM Transition Frequency (Pin 10) | $LRC_{Freq}$ | 247 | 273 | 309 | Hz |
| LRC Duty Cycle Increase Rate<br>Low RPM Mode ($LRC_{Freq}$ < 247 Hz),<br>Pin 11 = Open (Slow Rate)<br>Low RPM Mode ($LRC_{Freq}$ < 247 Hz),<br>Pin 11 = Grounded (Fast Rate)<br>High RPM Mode ($LRC_{Freq}$ > 309 Hz),<br>Pin 11 = Don't Care (LRC Mode is disabled) | <br>$LRC_S$<br><br>$LRC_F$<br><br>$LRC_H$ | <br>8.5<br><br>34<br><br>409 | <br>9.5<br><br>38<br><br>455 | <br>10.5<br><br>42<br><br>501 | <br>%/sec<br><br>%/sec<br><br>%/sec |

**NOTES:** 1. 125 ms wide square wave pulse.
2. Maximum time = 2 minutes.

10

**Figure 1. Simplified Application**

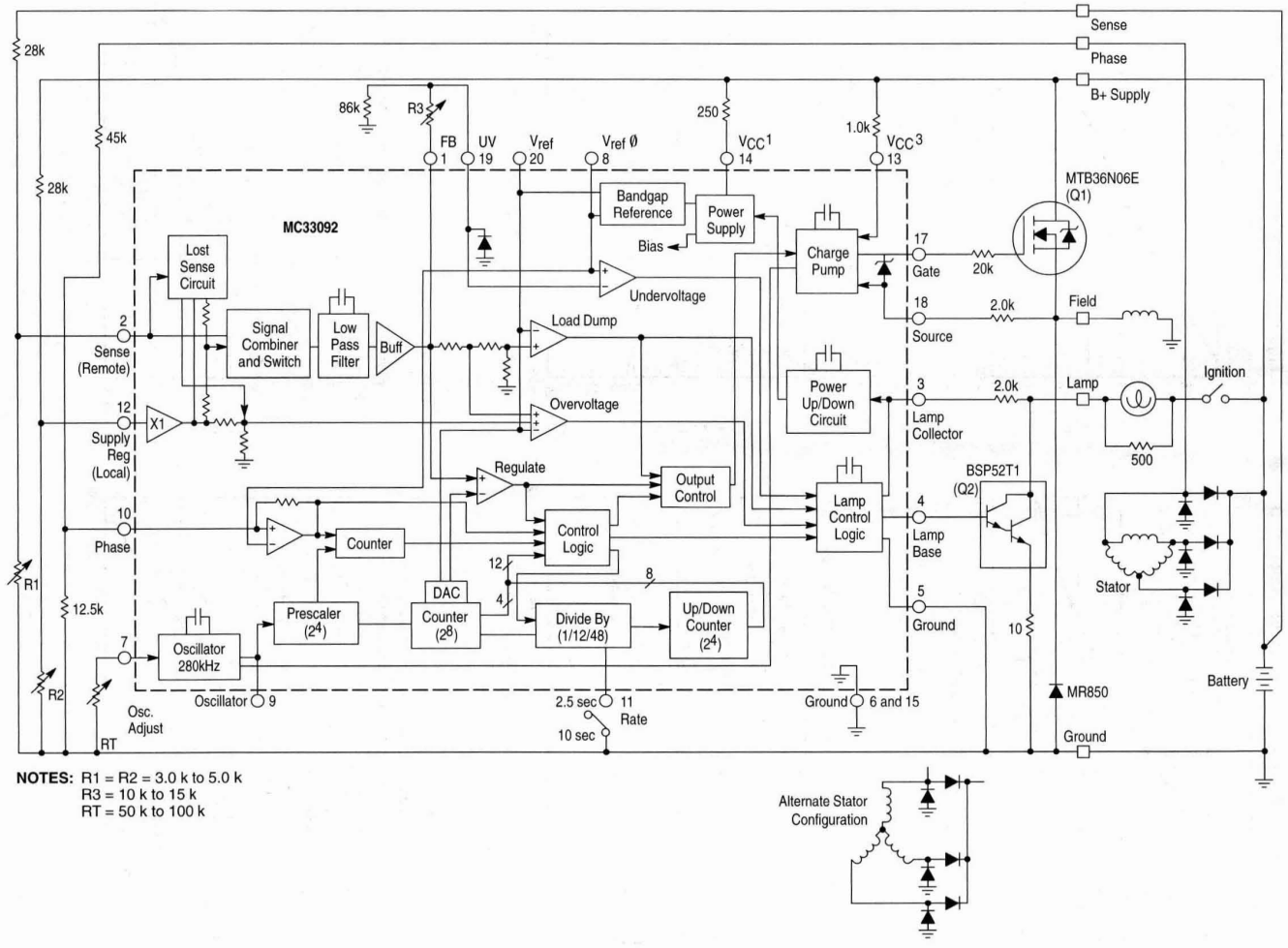


**Figure 2. Standby Current versus Temperature**

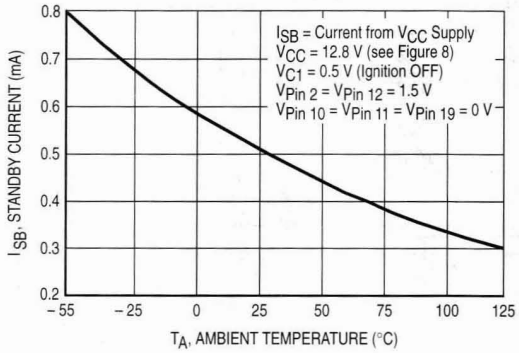

$I_{SB}$ = Current from $V_{CC}$ Supply
$V_{CC}$ = 12.8 V (see Figure 8)
$V_{C1}$ = 0.5 V (Ignition OFF)
$V_{Pin\ 2} = V_{Pin\ 12}$ = 1.5 V
$V_{Pin\ 10} = V_{Pin\ 11} = V_{Pin\ 19}$ = 0 V
$I_{SB}$, STANDBY CURRENT (mA)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
−55 −25 0 25 50 75 100 125
$T_A$, AMBIENT TEMPERATURE (°C)

**Figure 3. Turn–On Voltage versus Temperature**

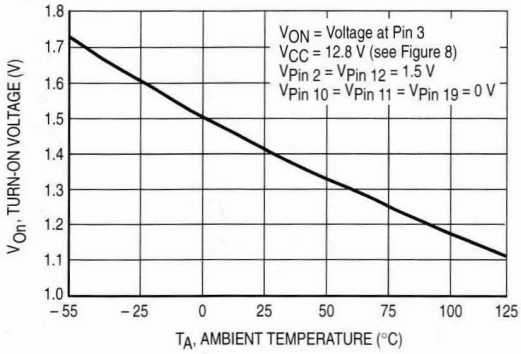



**Figure 4. Reference Voltage versus Temperature**

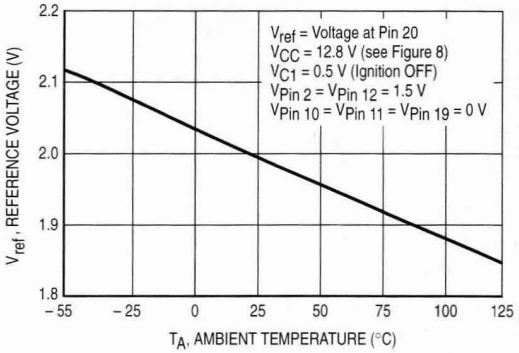
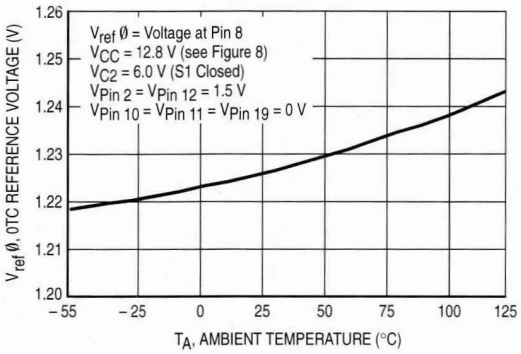

$V_{ref}$ = Voltage at Pin 20
$V_{CC}$ = 12.8 V (see Figure 8)
$V_{C1}$ = 0.5 V (Ignition OFF)
$V_{Pin\ 2} = V_{Pin\ 12}$ = 1.5 V
$V_{Pin\ 10} = V_{Pin\ 11} = V_{Pin\ 19}$ = 0 V
$V_{ref}$, REFERENCE VOLTAGE (V)
2.2
2.1
2.0
1.9
1.8
−55 −25 0 25 50 75 100 125
$T_A$, AMBIENT TEMPERATURE (°C)

**Figure 5. 0TC Reference Voltage versus Temperature**


$V_{ref}$ Ø = Voltage at Pin 8
$V_{CC}$ = 12.8 V (see Figure 8)
$V_{C2}$ = 6.0 V (S1 Closed)
$V_{Pin\ 2} = V_{Pin\ 12}$ = 1.5 V
$V_{Pin\ 10} = V_{Pin\ 11} = V_{Pin\ 19}$ = 0 V
$V_{ref}$ Ø, 0TC REFERENCE VOLTAGE (V)
1.26
1.25
1.24
1.23
1.22
1.21
1.20
−55 −25 0 25 50 75 100 125
$T_A$, AMBIENT TEMPERATURE (°C)

10

**Figure 6. Oscillator Frequency versus Timing Resistor**

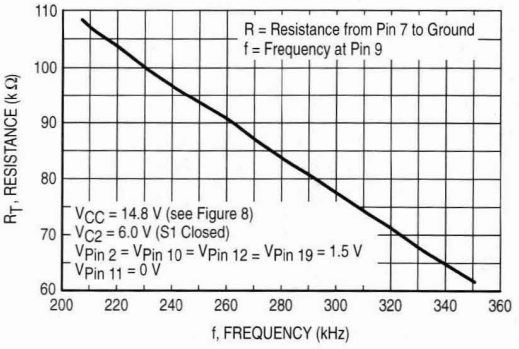

R = Resistance from Pin 7 to Ground
f = Frequency at Pin 9
$V_{CC}$ = 14.8 V (see Figure 8)
$V_{C2}$ = 6.0 V (S1 Closed)
$V_{Pin\ 2} = V_{Pin\ 10} = V_{Pin\ 12} = V_{Pin\ 19}$ = 1.5 V
$V_{Pin\ 11}$ = 0 V
$R_T$, RESISTANCE (k Ω)
110
100
90
80
70
60
200 220 240 260 280 300 320 340 360
f, FREQUENCY (kHz)

**Figure 7. Input Voltage versus Output Duty Cycle**

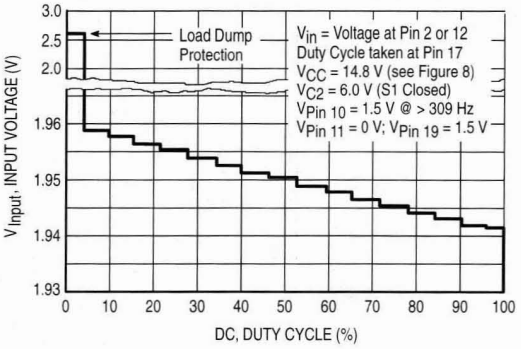
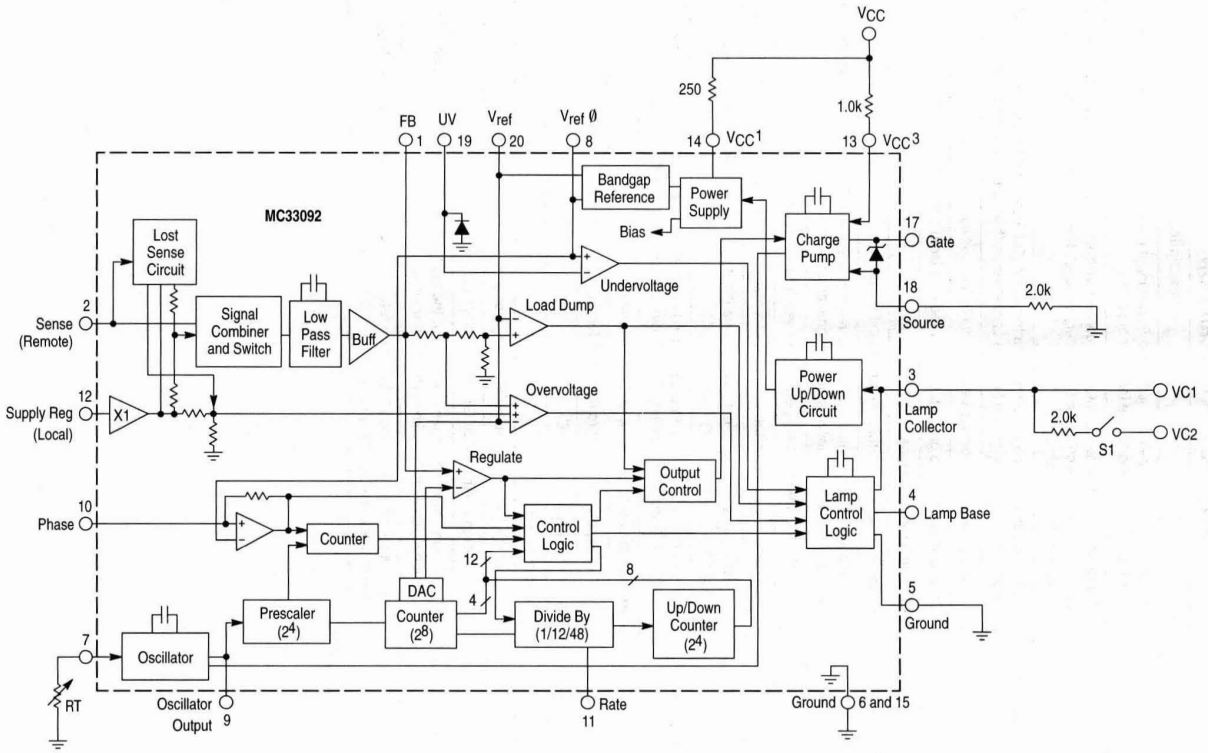

Load Dump Protection
$V_{in}$ = Voltage at Pin 2 or 12
Duty Cycle taken at Pin 17
$V_{CC}$ = 14.8 V (see Figure 8)
$V_{C2}$ = 6.0 V (S1 Closed)
$V_{Pin\ 10}$ = 1.5 V @ > 309 Hz
$V_{Pin\ 11}$ = 0 V; $V_{Pin\ 19}$ = 1.5 V
$V_{Input}$, INPUT VOLTAGE (V)
3.0
2.5
2.0
1.96
1.95
1.94
1.93
0 10 20 30 40 50 60 70 80 90 100
DC, DUTY CYCLE (%)

**Figure 8. Typical Test Circuit**



## PIN FUNCTION DESCRIPTION

| Pin No. | Function | Description |
|---|---|---|
| 1 | FB | This pin provides a filtered result of the Sense input (if the Sense input is used) or the Supply Regulation input (if the Sense input is not used). |
| 2 | Sense | The Sense input is a remote (Kelvin), low current battery voltage reference input used to give an accurate representation of the true battery voltage. This input is also used to monitor overvoltage or load dump conditions. |
| 3 | Lamp Collector and Power–Up/Down | This pin connects to the collector of the transistor (Q2) used to drive the fault lamp. It is also used to sense a closed ignition switch (voltage sense) which then turns power on to the IC. |
| 4 | Lamp Base | The Lamp Base pin provides base current to the fault lamp drive transistor (Q2). |
| 5 | Ground | Grounded to provide a ground return for the fault lamp control logic circuit. |
| 6, 15 | Ground | IC ground reference pins. |
| 7 | Oscillator Adjust | A resistor to ground on this pin adjusts the internal oscillator frequency (see Figure 6). |
| 8 | * $V_{ref}Ø$ | This is a test point for the 1.1 V to 1.4 V reference voltage. It has a zero temperature coefficient. The reference is used internally for phase signal and undervoltage detection. |
| 9 | * Oscillator | Test point for checking the operation of the internal oscillator. |
| 10 | Phase | The Phase input detects the existence of a magnetic field rotating within the alternator. |
| 11 | Rate | The Rate pin is used to select a slow mode (floating) or fast mode (ground) Load Response Control recovery rate. |
| 12 | Supply Regulation | The voltage on the Supply Regulation pin is used as a representation of the alternator output voltage. This input also used to monitor overvoltage or load dump conditions. |
| 13 | $V_{CC}3$ | Positive supply for the internal Charge Pump. |
| 14 | $V_{CC}1$ | Positive supply for the entire IC except for the Charge Pump. |
| 15, 6 | Ground | Ground reference for the IC. |
| 16 | N/C | No connection. |
| 17 | Gate | Controls the Gate of the MOSFET used to energize the field winding. |
| 18 | Source | Field winding control MOSFET source reference. |
| 19 | Undervoltage | If the voltage at this pin goes below 1.0 V, the fault lamp is guaranteed to turn on. The IC will continue to function, but with limited performance. |
| 20 | * $V_{ref}$ | Test point for the 1.7 V to 2.3 V Bandgap reference voltage. This voltage has a negative temperature coefficient of approximately –11 mV/°C. |

***NOTE:** Pins 8, 9 and 20 are test points only.

## APPLICATION CIRCUIT DESCRIPTION

### Introduction

The MC33092, designed to operate in a 12 V system, is intended to control the voltage in an automotive system that uses a 3 phase alternator with a rotating field winding. The system shown in Figure 1 includes an alternator with its associated field coil, stator coils and rectifiers, a battery, a lamp and an ignition switch. A tap is connected to one corner of the stator windings and provides an AC signal for rotation (phase) detection.

A unique feature of the MC33092 is the Load Response Control (LRC) circuitry. The LRC circuitry is active when the stator winding AC signal frequency (phase buffer input signal, Pin 10) is lower than the Low/High RPM transition frequency. When active, the LRC circuitry dominates the basic analog control circuitry and slows the alternator response time to sudden increases in load current. This prevents the alternator from placing a sudden, high torque load on the automobile engine when a high current accessory is switched on.

The LRC circuitry is inactive when the stator winding AC signal frequency is higher than the Low/High RPM transition frequency. When the LRC circuitry is inactive, the basic analog control circuitry controls the alternator so it will supply a constant voltage that is independent of the load current.

Both the LRC and analog control circuits control the system voltage by switching ON and OFF the alternator field current using Pulse Width Modulation (PWM). The PWM approach controls the duty cycle and therefore the average field current. The field current is switched ON and OFF at a fixed frequency by a MOSFET (Q1) which is driven directly by the IC. The MC33092 uses a charge pump to drive the MOSFET in a high side configuration for alternators having a grounded field winding.

A fault detector is featured which detects overvoltage, undervoltage, slow rotation or non–rotation (broken alternator belt) conditions and indicates them through a fault lamp drive output (Pin 4).

A Load Dump protection circuit is included. During a load dump condition, the MOSFET gate drive (Pin 17) and the fault lamp drive output are disabled to protect the MOSFET, field winding and lamp.

### Power–Up/Down

Power is continuously applied to the MC33092 through $V_{CC}1$ and $V_{CC}3$. A power–up/down condition is determined by the voltage on the Lamp Collector pin (Pin 3). When this voltage is below 0.5 V the IC is guaranteed to be in a low current standby mode. When the voltage at Pin 3 is above 2.0 V, the IC is guaranteed to be fully operational. The power–up voltage is applied to Pin 3 via the ignition switch and fault lamp. In case the fault lamp opens, a 500 Ω bypass resistor should be used to ensure regulator IC power–up.

A power–up reset circuit provides a reset or set condition for all digital counter circuitry. There is also a built–in power–up delay circuit that protects against erratic power–up signals.

### Battery and Alternator Output Voltage Sensing

The battery and the alternator output voltage are sensed by the remote (Sense, Pin 2), and the local (Supply Regulator, Pin 12) input buffer pins, respectively, by way of external voltage dividers. The regulated system voltage is determined by the voltage divider resistor values.

Normally the remote pin voltage determines the value at which the battery voltage is regulated. In some cases the remote pin is not used. When this condition ($V_{Pin\ 2} < 0.6$ V typically) exists, a sense loss function allows the local pin voltage to determine the regulated battery voltage with no attenuation of signal. If, however, when the remote pin is used, and the voltage at this pin is approximately 25% less than the voltage at the local sense pin (but greater than 0.6 V, typically), the value at which the battery voltage is regulated is switched to the local sense pin voltage (minus the 25%). The signal combiner/switch controls this transfer function.

### Low Pass Filter, DAC & Regulator Comparator

The output of the combiner/switch buffer feeds a low pass filter block to remove high frequency system noise. The filter output is buffered and compared by the regulator comparator to a descending ramp waveform generated by an internal DAC. When the two voltages are approximately equal, the output of the regulator comparator changes state and the gate of the MOSFET is pulled low (turned OFF) by the output control logic for the duration of the output frequency clock cycle. At the beginning of the next output clock cycle, the DAC begins its descending ramp waveform and the MOSFET is turned ON until the regulator comparator output again changes state. This ongoing cycle constitutes the PWM technique used to control the system voltage.

### Oscillator

The oscillator block provides the clock pulses for the prescaler–counter chain and the charge control for the charge pump circuit. The oscillator frequency is set by an external resistor from Pin 7 to ground as presented in Figure 6.

The prescaler–counter divides the oscillator frequency by $2^{12}$ (4096) and feeds it to the output control logic and divider–up/down counter chain. The output control logic uses it as the fundamental regulation output frequency (Pin 17).

### Load Response Control

The Load Response Control (LRC) circuit generates a digital control of the regulation function and is active when the stator output AC signal (Pin 10) frequency is lower than the Low/High RPM transition frequency. The LRC circuit takes the output signal of the prescaler–counter chain and with a subsequent divider and up/down counter to provide delay, controls the alternator response time to load increases on the system. The response time is pin programmable to two rates. Pin 11 programs the divider to divide by 12 or divide by 48. If Pin 11 is grounded, the signal fed to the up/down counter is divided by 12 and the response time is 12 times slower than the basic analog response time. If Pin 11 is left floating, the signal to the up/down counter is divided by 48 and the response time is 48 times slower.

The basic analog (LRC not active) and digital duty cycle control (LRC active) are OR'd such that either function will terminate drive to the gate of the MOSFET device with the shortest ON–time, i.e., lower duty cycle dominating.

The digital ON–time is determined by comparing the output of the up/down counter to a continuous counter and decoding when they are equal. This event will terminate drive to the MOSFET. A count direction shift register requires three consecutive clock pulses with a state change on the data input of the register to result in an up/down count direction change. The count will increase for increasing system load up to 100% duty cycle and count down for decreased loading to a minimum of 29% duty cycle. The analog control can provide a minimum duty cycle of 4 to 5%. The initial power–up duty cycle is 29% until the phase comparator input exceeds its input threshold voltage. Also, the IC powers up with the LRC circuit active, i.e., when the Lamp Collector pin exceeds the power–up threshold voltage.

**Fault Lamp Indicator**

Pins 3 and 4 control the external Darlington transistor (Q2) that drives the fault indicator lamp. A 10 Ω resistor should be placed in series with the transistor's emitter for current limiting purposes. The fault lamp is energized during any of the following fault conditions: 1) No Phase buffer (Pin 10) input due to slow or no alternator rotation, shorted phase winding, etc.; 2) Phase buffer input AC voltage less than the phase detect threshold; 3) Overvoltage on Pin 2, or Pin 12 if Pin 2 is not used, or 4) Undervoltage on Pin 19 with the phase buffer input signal higher than the Low/High RPM transition frequency.

**Phase Buffer Input**

A tap is normally connected to one corner of the alternator's stator winding to provide an AC voltage for rotation detection. This AC signal is fed into the phase buffer input (Pin 10) through a voltage divider. If the frequency of this signal is less than the phase rotation detect frequency (36 Hz, typically), the fault lamp is lit indicating an insufficient alternator rotation and the MOSFET drive (Pin 17) output duty cycle is restricted to approximately 29% maximum. Also, if the peak voltage of the AC signal is less than the phase detect threshold, the fault lamp is lit indicating an insufficient amount of field current and again the MOSFET drive (Pin 17) output duty cycle is restricted to approximately 29% maximum.

**Undervoltage, Overvoltage and Load Dump**

The low pass filter output feeds an undervoltage comparator through an external voltage divider. The voltage divider can be used to adjust the undervoltage detection level. During an undervoltage condition, the fault lamp will light only if the phase buffer input signal frequency is higher than the Low/High RPM transition frequency. This is to ensure that the undervoltage condition is caused by a true fault and not just by low alternator rotation. To help maintain system voltage regulation during an undervoltage condition, the output duty cycle is automatically increased to 100%. Even though the fault lamp may be energized for an undervoltage condition, the MC33092 will continue to operate but with limited performance.

Through an internal voltage divider, the low pass filter feeds an overvoltage comparator which monitors this output for an overvoltage condition. If the overvoltage threshold is exceeded, the fault lamp is lit and the MOSFET drive (Pin 17) output duty cycle is restricted to approximately 4% maximum.

The internal voltage divider on the input to the load dump comparator has a different ratio than the divider used on the overvoltage comparator. This allows the load dump detect threshold to be higher than the overvoltage threshold even though both comparators are monitoring the same low pass filter output. If the load dump detect threshold is exceeded, the fault lamp and MOSFET drive outputs are disabled to protect the MOSFET, field winding and lamp.

MOTOROLA

*Advance Information*

# Dual High-Side Switch

**MC33143**

**DUAL HIGH–SIDE SWITCH**

**SEMICONDUCTOR TECHNICAL DATA**

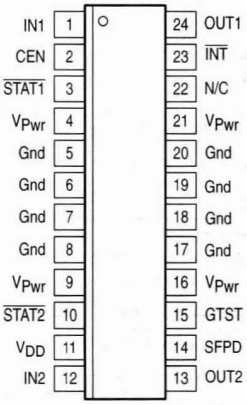
The MC33143 is a dual high–side switch designed for solenoid control in harsh automotive applications, but is well suited for other environments. The device can also be used to control small motors and relays as well as solenoids. The MC33143 incorporates SMARTMOS™ technology, with CMOS logic, bipolar/MOS analog circuitry, and DMOS power outputs. An internal charge pump is incorporated for efficient gate enhancement of the internal high–side power output devices. The outputs are designed to provide current to low impedance solenoids. The MC33143 provides individual output fault status reporting along with internal Overcurrent and Over Temperature protection. The device also has Overvoltage protection, with automatic recovery, which "globally" disables both outputs for the duration of an Overvoltage condition. Each output has individual Overcurrent and Over Temperature shutdown with automatic retry recovery. Outputs are enabled with a CMOS logic high signal applied to an input to providing true logic control. The outputs, when turned on, provide full supply (battery) voltage across the solenoid coil.

The MC33143 is packaged in an economical 24 pin surface mount power package and specified over an operating voltage of 5.5 V ≤ $V_{Pwr}$ < 26 V for –40°C ≤ $T_A$ ≤ 125°C.

- Designed to Operate Over Wide Supply Voltages of 5.5 V to 26 V
- Dual High–Side Outputs Clamped to –10 V for Driving Inductive Loads
- Internal Charge Pump for Enhanced Gate Drive
- Interfaces Directly to a Microcontroller with Parallel Input Control
- Outputs Current Limited to 3.0 A to 6.0 A for Driving Incandescent Loads
- Chip Enable "Sleep Mode" for Power Conservation
- Individual Output Status Reporting
- $\overline{\text{Fault}}$ Interrupt Output for System Interrupt Use
- Output ON or OFF Open Load Detection
- Overvoltage Detection and Shutdown
- Output Over Temperature Detection and Shutdown with Automatic Retry
- Sustained Current Limit or Immediate Overcurrent Shutdown Output Modes
- Output Short to Ground Detection and Shutdown with Automatic Retry
- Output Short to $V_{Pwr}$ Detection

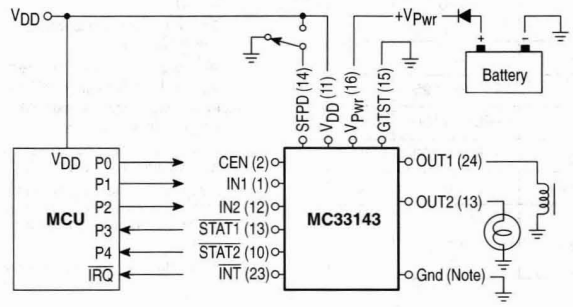
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
(SOP (16+4+4)L)

**PIN CONNECTIONS**




(Top View)

**Simplified Application**




**NOTE:** Pins 5, 6, 7, 8, 17, 18, 19 and 20 provide electrical ground and heatsinking.

This device contains 889 active transistors.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33143DW | $T_A$ = – 40° to +125°C | SOP–24L |

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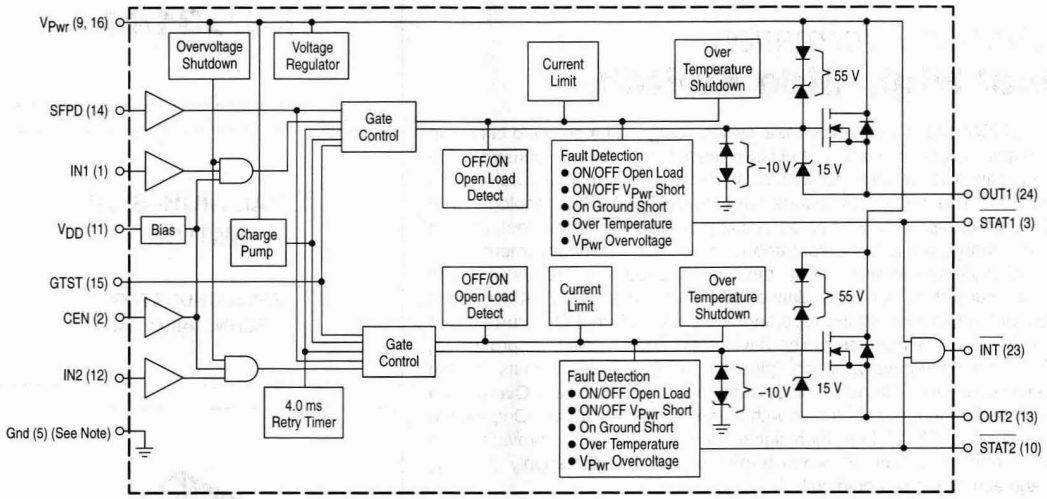
**Figure 1. Simplified Internal Block Diagram**




**NOTE:** Pins 5, 6, 7, 8, 17, 18, 19 and 20 should all be grounded so as to provide electrical as well as thermal heatsinking of the device.

**MAXIMUM RATINGS** (All voltages are with respect to ground, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage<br>Steady State Continuous Operation<br>Negative Transient (Note 1)<br>Positive Load Dump Transient (Note 2) | $V_{Pwr}$ | <br>26<br>–1.5<br>60 | V |
| Logic Supply Voltage Range | $V_{DD}$ | –0.3 to 7.0 | V |
| Logic Supply Current | $I_{DD}$ | 5.0 | mA |
| Input Voltage (Note 3) | $V_{in}$ | –0.3 to 7.0 | V |
| Output Clamp Voltage<br>$I_O$ = –20 mA<br>$I_O$ = –200 mA | $V_{Clamp}$ | <br>–3.0 to –20<br>–5.5 to –20 | V |
| Output Current Limit (Note 4) | $I_{O(Lim)}$ | –3.0 to –6.0 | A |
| Output Clamp Energy ($I_O$ = –1.0 A)<br>$T_J$ = 25°C<br>$T_J$ = 125°C | $E_{Clamp}$ | <br>300<br>100 | mJ |
| ESD (Minimum)<br>Human Body Model (Note 5)<br>Machine Model (Note 6) | <br>HBM<br>MM | <br>2000<br>200 | V |
| Power Dissipation ($T_A$ = 25°C) (Note 7) | $P_D$ | 4.2 | W |
| Operating Temperature (Note 8) | $T_A$ | –40 to +125 | °C |
| Operating Junction Temperature | $T_J$ | –40 to +150 | °C |
| Storage Temperature | $T_{stg}$ | –55 to +150 | °C |
| Soldering Temperature (for 10 Seconds) | $T_{solder}$ | 270 | °C |
| Thermal Resistance<br>Junction–to–Lead<br>Junction–to–Ambient | <br>$R_{\theta JL}$<br>$R_{\theta JA}$ | <br>15<br>30 | °C/W |

**NOTES:**
1. Negative transient survival capability for 100 ms time duration.
2. Positive transient survival capability with typical automotive load dump condition; 400 ms time constant decay.
3. All input pins (IN1–2, CEN and SFPD).
4. Each output has independent current limiting.
5. Performed in accordance to HBM; $C_{Zap}$ = 100 pF, $R_{Zap}$ = 1500 Ω.
6. Performed in accordance to MM; $C_{Zap}$ = 100 pF, $R_{Zap}$ = 0 Ω.
7. Derate Power Dissipation 33 mW/°C for temperatures above 25°C.
8. Ambient temperature is given as a practical reference; Maximum junction temperature is the limiting factor.
9. ESD data available upon request.

**DC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{Pwr}$ ≤ 17 V, 4.5 V ≤ $V_{DD}$ 5.5 V, −40°C ≤ $T_L$ ≤ 125°C, unless otherwise noted, typical values represent approximate mean at $T_L$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER INPUT** | | | | | |
| Supply Voltage Range (Operational) | $V_{Pwr}$ | 9.0 | – | 17 | V |
| Supply Current (Note 1)<br>Both Outputs ON<br>(CEN = IN1 = IN2 = 0.7 x $V_{DD}$, $I_{O1}$ = $I_{O2}$ = −1.0 A)<br>Standby (CEN = 0.7 x $V_{DD}$, IN1 = IN2 = 0.3 x $V_{DD}$, $R_L$ = 12 Ω)<br>"Sleep State" (CEN = IN1 = IN2 = 0.3 x $V_{DD}$, $R_L$ = 12 Ω) | <br><br>$I_{Pwr}$<br>$I_{Pwr(sby)}$<br>$I_{Pwr(sleep)}$ | <br><br>0.1<br>–<br>– | <br><br>4.2<br>3.9<br>0.2 | <br><br>7.0<br>7.0<br>300 | <br><br>mA<br>mA<br>µA |
| Logic Supply Voltage Range | $V_{DD}$ | 4.5 | – | 5.5 | V |
| Logic Supply Current<br>Both Outputs ON (IN1 = IN2 = 0.7 x $V_{DD}$, $I_{O1}$ = $I_{O2}$ = −1.0 A) | $I_{DD}$ | – | 0.43 | 5.0 | mA |
| Overvoltage Shutdown (Note 2) | $V_{Pwr(ovsd)}$ | 30 | 33.2 | 38 | V |
| Overvoltage Shutdown Hysteresis | $V_{Pwr(hys)}$ | 0.3 | 0.5 | 1.5 | V |

**NOTES:** 1. Supply current when both outputs are ON and during standby are measured in the Ground pin while during "sleep state" is measured in the $V_{Pwr}$ pin.
2. Overvoltage Shutdown causes enabled outputs to be forced OFF; Overvoltage fault is immediately reported.

**DC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{Pwr}$ ≤ 17 V, 4.5 V ≤ $V_{DD}$ 5.5 V, −40°C ≤ $T_L$ ≤ 125°C, unless otherwise noted, typical values represent approximate mean at $T_L$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER OUTPUT** | | | | | |
| Drain–to–Source ON Resistance (Note 1)<br>($T_J$ = 25°C, CEN = IN1 = IN2 = 0.7 x $V_{DD}$)<br>$I_O$ = −0.5 A. $V_{Pwr}$ = 5.5 V<br>$I_O$ = −1.0 A. $V_{Pwr}$ = 14 V<br>$I_O$ = −2.0 A. $V_{Pwr}$ = 24 V | $R_{DS(on)}$ | <br><br>–<br>–<br>– | <br><br>0.2<br>0.14<br>0.14 | <br><br>0.5<br>0.2<br>0.2 | Ω |
| Drain–to–Source ON Resistance (Note 1)<br>($T_J$ = 125°C, CEN = IN1 = IN2 = 0.7 x $V_{DD}$)<br>$I_O$ = −0.5 A. $V_{Pwr}$ = 5.5 V<br>$I_O$ = −1.0 A. $V_{Pwr}$ = 14 V<br>$I_O$ = −2.0 A. $V_{Pwr}$ = 24 V | $R_{DS(on)}$ | <br><br>–<br>–<br>– | <br><br>–<br>–<br>– | <br><br>1.0<br>0.38<br>0.38 | Ω |
| Output Self–Limiting Current (Note 2)<br>(CEN = IN1 = IN2 = SFPD = 0.7 x $V_{DD}$, $R_L$ = 0 Ω) | $I_{O(Lim)}$ | −3.0 | −4.1 | −6.0 | A |
| Output OFF Leakage Current<br>(CEN = 0.7 x $V_{DD}$, IN1 = IN2 = 0.3 x $V_{DD}$) | $I_{O(Lkg)}$ | −5.0 | −45 | −150 | µA |
| Output OFF Open Load Sense Current<br>(CEN = 0.7 x $V_{DD}$, IN1 = IN2 = 0.3 x $V_{DD}$) | $I_{O(Sense)}$ | −5.0 | −45 | −150 | µA |
| Output ON Open Load Detection Current (Note 3)<br>(CEN = IN1 = IN2 = 0.7 x $V_{DD}$)<br>$T_L$ = −40°C<br>$T_L$ = 125°C | $I_{O(On)}$ | <br>−2.0<br>−2.0 | <br>−145<br>−181 | <br>−200<br>−200 | mA |
| Output Clamp Voltage (Note 4)<br>(CEN = 0.7 x $V_{DD}$, IN1 = IN2 = 0.3 x $V_{DD}$)<br>$I_O$ = −20 mA<br>$I_O$ = −200 mA | $V_{Clamp}$ | <br>−9.0<br>−9.0 | <br>−13.2<br>−13.5 | <br>−20<br>−20 | V |
| Over Temperature Shutdown Range (Note 5)<br>(CEN = IN1 = IN2 = SFPD = 0.7 x $V_{DD}$) | $T_{Lim}$ | 155 | – | 185 | °C |
| Over Temperature Shutdown Hysteresis (Note 6) | $T_{Lim(hys)}$ | – | – | 15 | °C |

**NOTES:** 1. $R_{DS(on)}$ applies to OUT1, OUT2 and is independent of output current.
2. Applies to each output; each output has independent self–limiting source current feature; Over Current and Short–to–Ground defined as condition when output source current exceeds $I_{O(Lim)}$; Device ignores Over Current and Short–to–Ground faults from 0 to $t_{ss}$.
3. Applies to each output; tested for by ramping $I_O$ from 0 until STAT ≤ 0.7 x $V_{DD}$; defined as the condition when $I_O$ is outside of $I_{O(on)}$ current window.
4. Applies to each output; each output has independent dynamic output voltage clamping feature.
5. Applies to each output; each output has independent thermal shutdown; parameter is measured by ramping temperature until enabled output is disabled; parameter is established by design but is not production tested; thermal fault is immediately reported.
6. Parameter is established by design but is not production tested.

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**DC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{Pwr}$ ≤ 17 V, 4.5 V ≤ $V_{DD}$ 5.5 V, –40°C ≤ $T_L$ ≤ 125°C, unless otherwise noted, typical values represent approximate mean at $T_L$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **CONTROL INTERFACE** | | | | | |
| Input Control | | | | | $V_{DD}$ |
| Logic High ($I_O$ = –0.1 A) (Note 1) | $V_{IH}$ | 0.7 | 0.56 | – | |
| Logic Low ($I_O$ = 0) (Note 2) | $V_{IL}$ | – | 0.52 | 0.3 | |
| Input Logic Voltage Hysteresis ($V_{IH}$ – $V_{IL}$) | $V_{hys}$ | 50 | 250 | 500 | mV |
| Input Pull–Down Current (0.3 x $V_{DD}$ ≤ $V_{in}$ < 0.7 x $V_{DD}$) (Note 3) | $I_{in(pd)}$ | 20 | 44 | 100 | µA |
| Chip–Enable Threshold | | | | | $V_{DD}$ |
| Logic Low (Note 4) | $V_{CEN(IL)}$ | – | 0.5 | 0.3 | |
| Logic High (Note 5) | $V_{CEN(IH)}$ | 0.7 | 0.5 | – | |
| Chip–Enable Hysteresis ($V_{CEN(IH)}$ – $V_{CEN(IL)}$) | $V_{CEN(hys)}$ | 50 | 150 | 500 | mV |
| Chip–Enable Pull–Up Current (CEN = 0.7 x $V_{DD}$) | $I_{CEN(pu)}$ | –2.0 | –16.8 | –40 | µA |
| Status Low Voltage ($I_{in}$ = 600 µA) (Note 6) | $V_{\overline{STAT}(low)}$ | – | 0.07 | 0.2 | $V_{DD}$ |
| Status Pull–Up Current (Note 7) | $I_{\overline{STAT}(pu)}$ | –20 | –44 | –100 | µA |
| Interrupt (Note 8) | | | | | $V_{DD}$ |
| Logic High | $\overline{INT}_h$ | 0.7 | – | – | |
| Logic Low | $\overline{INT}_l$ | – | – | 0.3 | |

**NOTES:** 1. Upper logic threshold voltage applies to IN1, IN2, and SFPD and expressed in $V_{DD}$ units

2. Lower logic threshold voltage applies to IN1, IN2, and SFPD and expressed in $V_{DD}$ units.

3. Applies to IN1, IN2, and SFPD.

4. Initially have CEN = 0.7 x $V_{DD}$, Ramp CEN down from $V_{DD}$ until $I_O$ = 0 and note disabling point.

5. Initially have $V_{in}$ = 0.7 x $V_{DD}$, Ramp CEN up from ground until $I_O$ = 0.1 A and note enabling point.

6. Applies equally to STAT1–2 and INT outputs; Measured threshold voltage by applying an "open" fault to OUT1 or OUT2 while forcing 600 µA of current into STAT1–2 or INT.

7. Measured with no faults on OUT1–2, $V_{\overline{STAT}}$ = $V_{\overline{INT}}$ = 0.8 x $V_{DD}$.

8. The Interrupt output has an internal active current pull–up.

**DC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{Pwr}$ ≤ 17 V, 4.5 V ≤ $V_{DD}$ 5.5 V, –40°C ≤ $T_L$ ≤ 125°C, unless otherwise noted, typical values represent approximate mean at $T_L$ = 25°C.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OUTPUT DYNAMICS** | | | | | |
| Output Short Sense Time (Note 1) | $t_{ss}$ | 30 | 54 | 100 | µs |
| Output Short Refresh Time (Note 2) | $t_{ref}$ | 3.0 | 4.1 | 6.0 | ms |
| Output Open Sense ON Time (Note 3) | $t_{os(on)}$ | 3.0 | 6.4 | 12 | ms |
| Output Propagation Delay | | | | | µs |
| Turn–On (Output Low to High) (Note 4) | $t_{dlh}$ | – | 7.2 | 50 | |
| Turn–Off (Output High to Low) (Note 5) | $t_{dhl}$ | – | 40 | 75 | |
| Output Slew Rate | | | | | V/µs |
| Output Rising (Note 6) | $SR_r$ | 0.2 | 11 | 10 | |
| Output Falling (Note 7) | $SR_f$ | 0.2 | 2.6 | 10 | |

**NOTES:** 1. CEN = 0.7 x $V_{DD}$, SFPD = 0.3 x $V_{DD}$, $R_L$ = 0, Step $V_{in}$ from 0.3 x $V_{DD}$ to 0.7 x $V_{DD}$; Sense time measured from step until $\overline{STAT}$ = 0.2 x $V_{DD}$.

2. CEN = IN1 = IN2 = 0.7 x $V_{DD}$, $R_L$ = 0; Refresh time measured from output disable until output is re–enabled.

3. $R_L$ = "open", Step $V_{in}$ from ground to 0.7 x $V_{DD}$, Open sense time measured from step until $V_{\overline{STAT}}$ ≤ 0.2 x $V_{DD}$.

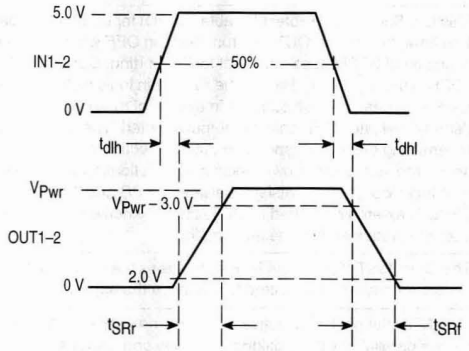
4. $R_L$ = 12 Ω, $C_L$ = 0.01 µF, step $V_{in}$ from $V_{IL}$ to $V_{IH}$; Turn–On propagation measured from $V_{in}$ = 0.5 x $V_{DD}$ until $V_{out}$ = 2.0 V (see Figure 2).

5. $R_L$ = 12 Ω, $C_L$ = 0.01 µF, step $V_{in}$ from $V_{IH}$ to $V_{IL}$; Turn–Off propagation measured from $V_{out}$ = $V_{Pwr}$ –3.0 V until $V_{out}$ = 2.0 V (see Figure 2).

6. $R_L$ = 12 Ω, $C_L$ = 0.01 µF, step $V_{in}$ from $V_{IL}$ to $V_{IH}$; Output Slew Rate measured from 2.0 V to $V_{Pwr}$ – 3.0 V (see Figure 2).

7. $R_L$ = 12 Ω, $C_L$ = 0.01 µF, step $V_{in}$ from $V_{IH}$ to $V_{IL}$; Output Slew Rate measured from $V_{Pwr}$ – 3.0 V to 2.0 V (see Figure 2).

**Figure 2. Output Response Waveform**




## PIN FUNCTION DESCRIPTION

| Pin | Symbol | Description |
|---|---|---|
| 1, 12 | IN1, IN2 | INput 1 and INput 2 (IN1 and IN2) respectively determine the state of the corresponding output drivers (OUT1 and OUT2) under normal operating conditions. When an input is high, it's corresponding output is active ON, and when low is disabled OFF. IN1 and IN2 have internal active pull–downs which allow a floating input pin to be conservatively interpreted as a logic low, turning Off the output. An unused input should be connected to ground. |
| 2 | CEN | Chip Enable (CEN) input pin, when low, disables both outputs (OUT1 and OUT2) and places the device in a "sleep mode" reducing the bias current required from $V_{DD}$ and $V_{Pwr}$. A falling edge of CEN causes OUT1 and OUT2 to rapidly turn OFF. A falling edge of CEN should precede any $V_{DD}$ shutdown to allow time OUT1 and OUT2 to be disabled. When CEN is low, INTerrupt ($\overline{INT}$) and STATus 1 and 2 ($\overline{STAT1–2}$) will be tri–stated (high impedance). The CEN pin can also be used for power–on reset and under voltage lockout to disable the outputs for power supply voltages less than 4.5 V. CEN is a dependent input from the system microcontroller unit (MCU) or some other integrated circuit. It has an internal pull–up resistor to $V_{DD}$ affording a floating pin to be interpreted as a logic high. $R_{pull–up}$ is greater than 50 kΩ. If used externally, this pin should be connected to $V_{DD}$. |
| 3, 10 | $\overline{STAT1}$. $\overline{STAT2}$ | The STATus pins ($\overline{STAT1–2}$) respectively indicate the presence of faults on OUT1–2. $\overline{STAT1–2}$ will be logic high during normal operation. A logic low will occur whenever an Open Load, Short–to–Ground, Short–to–Supply (Battery), Thermal Limit, or Overvoltage Shutdown fault condition is experienced on a corresponding output. $\overline{STAT1–2}$ are both active low digital drivers. A 10 kΩ resistor between $\overline{STAT1–2}$ and the system CPU may improve a Failure Mode Evaluation Analysis (FMEA) score if $\overline{STAT1–2}$ are externally shorted to $V_{Pwr}$. If unused, this pin should be left connected. |
| 4, 9, 16, 21 | $V_{Pwr}$ | These pins are connected to the supply and provide load current to the DMOS outputs, are used pumping the DMOS gates, and for Overvoltage shutdown detection of the DMOS. The DMOS outputs will turn ON with 5.5 to 24 V applied to $V_{Pwr}$. $V_{Pwr}$ is limited to –1.5 V for a maximum duration of 250 ms. A 10 nF de–coupling cap is recommended to be used from $V_{Pwr}$ to Ground. |
| 5, 6, 7, 8, 17, 18, 19, 20 | Gnd | These eight pins constitute the circuits ground (Gnd) and also provide heatsinking for the DMOS output transistors. Ground continuity is required for the outputs2 to turn ON. |
| 11 | $V_{DD}$ | This pin is to be connected to the 5.0 V logic supply of the system. A 10 nF de–coupling capacitor is recommended from $V_{DD}$ to Gnd. |
| 13, 24 | OUT1, OUT2 | These pins are connected internally to the DMOS output transistors which source current into the corresponding load. Each output incorporates dynamic clamping to accommodate inductive loads. In addition, each output has independent short to ground detection and protection, current limit detection and protection, thermal limit detection and protection, ON open load and or short to supply (battery) detection. Neither output will turn ON if CEN is logic low. An unused output should be connected to a 10 kΩ load to prevent false fault reporting. A 1.0 nF filter capacitor may be used from OUT to Gnd to provide dV/dt noise filtering. |

**PIN FUNCTION DESCRIPTION (continued)**

| Pin | Symbol | Description |
|---|---|---|
| 14 | SFPD | This is a Short Fault Protect Disable (SFPD) input; which when logic high disables the internal current limit timer preventing OUT1–2 from latching OFF when confronted with an overcurrent condition. The condition of SFPD does not affect fault reporting. Current and thermal limit remain active when the SFPD pin is logic high. Having the SFPD pin logic high facilitates the device to drive incandescent lamp loads with peak in–rush currents in excess of three amperes. When SFPD is logic low, an overcurrent demand will latch OFF only the output affected. The device will then automatically begin active re–enabling of the corresponding output affected for the duration of the overcurrent condition. SFPD has an internal active pull–down which affords a floating input pin condition to be conservatively interpreted as a logic low. A 10 kΩ resistor between SFPD and the system CPU may improve the FMEA score if SFPD is externally shorted to OUT2. SFPD should be connected to Gnd or $V_{DD}$ for the desired operating mode and not be left "floating". |
| 15 | GTST | The Gate TeST (GTST) pin is used to stress the devices DMOS gates during testing operations. This pin should normally be connected to ground in the application. |
| 23 | $\overline{INT}$ | The INTerrupt pin $\overline{INT}$ is active logic low and indicates the presence of a fault on either the output. $\overline{INT}$ can be paralleled with additional fault pins and used as a system CPU interrupt to indicate the presence of a fault. The system CPU can then read $\overline{STAT1–2}$ to determine the specific type of fault occurring. $\overline{INT}$ will be logic high during normal operation. A logic low will result if a fault occurs on either OUT1 or OUT2. $\overline{INT}$ has an internal active pull–up and requires no external pull–up resistor to be used. The $\overline{INT}$ output has sufficient current drive capability to afford paralleling of up to five $\overline{INT}$ pins. A 10 kΩ resistor between $\overline{INT}$ and the system CPU may improve the FMEA score if $\overline{INT}$ is externally shorted to OUT1. This pin should be left unconnected if the feature is not used. |

**Figure 3. Function Table**

| Device Condition | In | Out | $\overline{STAT}$ | Output Condition | $\overline{STAT}$ Condition |
|---|---|---|---|---|---|
| Normal | Low | Low | High | Normal OFF | Normal |
| | High | High | High | Normal ON | Normal |
| Output to Gnd Short | Low | Low | High | Normal OFF | Normal |
| | High | High/Low | Low | Output in active retry mode. Normal ON when short is removed. | Short fault reported. Fault clears when short is removed. |
| Open Load | Low | High | Low | Normal OFF | "OFF" open fault reported. Fault clears when load is connected. |
| | High | High | Low | Normal ON | "ON" open fault reported. Fault clears when load is connected. |
| Output to $V_{Pwr}$ Short | Low | High | Low | Normal OFF | "OFF" open fault reported. Fault clears when short is removed. |
| | HIgh | High | Low | Normal ON | "ON" open fault reported. Fault clears when short is removed. |
| Over Temperature | Low | Low | Low | Normal OFF | Thermal fault reported. Fault clears with no thermal limit. |
| | High | Low | Low | Output disabled. Output Retries with no thermal limit. | Thermal fault reported. IN low and no thermal limit required to clear the fault. |
| $V_{Pwr}$ Overvoltage | Low | Low | Low | Normal OFF | Overvoltage fault reported. Fault clears with no overvoltage. |
| | High | Low | Low | Output disabled. Will reset with no overvoltage. | Overvoltage fault reported. Fault clears with no overvoltage. |
| "Sleep"/Under Voltage Mode, CEN Low | Low | Low | High–Z | Output disabled. | STAT tri–stated, no faults reported. |
| | High | Low | High–Z | Output disabled. | STAT tri–stated, no faults reported. |

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## FUNCTIONAL DESCRIPTION

### General

The MC33143 is designed as an interface device; between system's electronic control unit and the actuators. It is designed to withstand several abnormal operating conditions, with the capability of reporting it's operating status back to the control unit. The MC33143 will resume normal operation after having experienced 60 V transients on the $V_{Pwr}$ line, output shorts to $V_{Pwr}$, open loads, output shorts to ground, over current, over temperature, or overvoltage conditions. Status information is available when ever a load experiences any of the faults. In addition, the MC33143 device incorporates internal output transient clamps allowing it to control inductive loads and survive negative voltage spikes without the need of external components.

### Power Supply Voltage Requirements

The MC33143 is designed to operate with 5.5 V to 26 V applied to the power supply pin ($V_{Pwr}$) and 4.5 V to 5.5 V applied to the logic supply pin ($V_{DD}$). If $V_{Pwr}$ is above the specified Overvoltage Shutdown voltage limit ($V_{Pwr(ovsd)}$) the outputs will be disabled and the status line voltage will transition to a low logic state indicating a fault.

When the CEN voltage is at a low logic state, OUT1 and OUT2 will turn OFF. This provides an under voltage shutdown for $V_{Pwr}$ in the 0 to 4.5 V range. The active low under voltage must be externally provided to the CEN pin.

The MC33143 is designed to survive the loss of $V_{Pwr}$.

### Normal Operations

The MC33143 is considered to be operating normal when the following conditions are met:

8) 5.5 V ≤ $V_{Pwr}$ ≤ 26 V.
9) –40°C ≤ TJ ≤ 150°C.
10) When load currents ($I_O$) exceed the Output Open "ON" detection current ($I_{O(on)}$) and occur within the Open Sense "ON" time ($t_{os(on)}$) window.
11) When load currents ($I_O$) are less than the Output Limit Current ($I_{O(Lim)}$) for durations in excess of the Short Sense time ($t_{ss}$).
12) So long as the output of the device is able to clamp negative voltages produced when switching inductive loads to the specified clamp voltage ($V_{Clamp}$).

### Fault Conditions

Anytime the MC33143 is not operating normal it is said to be operating in a "faulted condition". Fault conditions will result in level changes of the status outputs ($\overline{STAT1–2}$) and disable the affected faulted output.

### Output Over Current/Short to Ground Faults

For an enabled input, the status line voltage will transition to a low logic level if the output current equals or exceeds the Output Limit current ($I_{O(Lim)}$) for a period of time in excess of the Short Sense time ($t_{ss}$). Only the affected output will turn off; independent of the corresponding input's condition. The device incorporates an internal short duration Refresh timer ($t_{ref}$) to mask edge transients due to switching noise. The output will remain off for the short $t_{ref}$ duration and then attempt to re–energize the shorted load. The internal protection circuitry continues to be active during this process. If the short is not removed; the circuitry will sequence and the output will remain off for a another $t_{ref}$ time. This process will continue so long as the output remains shorted and the input remains in a logic high state. If the short is removed from the output, while the input is ON, the MC33143 will return to normal operation and the status line will go to a logic high state after the $t_{ref}$ time–out. The status line will also go to a logic high state on the falling edge of the corresponding input.

### Open Load/Short to $V_{Pwr}$ Fault

This condition is commonly referred to as an "ON" open fault. For this fault to be present, the output current of the driver must be at or near zero. Since the MC33143 is a "high–side switch"; It is for this reason a Short to $V_{Pwr}$ fault resembles an Open Load fault, in so far as the MC33143 is concerned. When this fault is present the status line voltage will transition to a low logic level so long as the output current does not exceed the specified Open ON detection current ($I_{O(on)}$) for a duration in excess of the specified Open Sense ON time ($t_{os(on)}$). If the open load or output short to $V_{Pwr}$ condition is removed, and the corresponding input is at a logic high state, the status line voltage will go to a logic high state after the drain current has exceeded $I_{O(on)}$. The ON open fault detection circuit incorporates a voltage comparator which monitors the voltage difference from $V_{Pwr}$ to OUT. When ever the $V_{Pwr}$ to OUT voltage difference falls below 10 mV an ON Open fault is reported. A Short to $V_{Pwr}$ external to any module the MC33143 is in will not be detected as an ON Open fault if the voltage difference from $V_{Pwr}$ to OUT is greater than 10 mV. $V_{Pwr}$ line voltage drops directly impact this detection ability.

### Overvoltage Fault

When this fault is present the status line voltage will transition to a logic low state when $V_{Pwr}$ exceeds the specified Overvoltage Shutdown threshold $V_{Pwr(ovsd)}$. This fault produces a "global" response on the part of the MC33143 by turning OFF both outputs independent of input conditions. The outputs will resume normal operation when $V_{Pwr}$ drops the specified Overvoltage Hysteresis $V_{Pwr(hys)}$ value.

### Over Temperature Fault

When this fault is present the status line voltage transitions to a low logic level when the junction temperature of either output exceeds the specified Thermal Limit threshold ($T_{Lim}$). Only the specific faulted output will shutdown independent of the input condition. The other output will continue to operate in a normal fashion unless it also becomes faulted. The thermally faulted output will resume normal operation when the junction temperature drops the specified Over Temperature Shutdown Hysteresis ($T_{Lim(hys)}$) amount.

MOTOROLA

# MC33192

# MI-Bus Interface Stepper Motor Controller

The MC33192 Stepper Motor Controller is intended to control loads in harsh automotive environments using a serial communication bus. The MI–Bus can provide satisfactory real time control of up to eight stepper motors. MI–Bus technology offers a noise immune system solution for difficult control applications involving relay drivers, motor controllers, etc.

The MC33192 stepper motor controller provides four phase signals to drive two phase motors in either half or full step modes. When used with an appropriate Motorola HCMOS microprocessor it provides an economical solution for applications requiring a minimum amount of wiring and optimized system versatility.

The MC33192 is packaged in an economical 16 pin surface mount package and specified at an operating voltage 12 V for – 40°C ≤ $T_A$ ≤ 100°C.

- Single Wire Open Bus Capability Up to 10 Meters in Length
- Programmable Address Bus System
- Fault Detection of Half–Bridge Drivers and Motor Windings
- Ceramic Resonator For Accurate and Reliable Transmission of Data
- Sub–Multiple of Oscillator End–of–Frame Signal
- MI–Bus Signal Slew Rate Limited to 1.0 V/μs for Minimum RFI
- MI–Bus Error Diagnostics
- Non–Functioning Device Diagnotics
- Over Temperature Detection
- Address Programming Sequence Status
- Load and Double Battery (Jump Start) Protection

**MI–BUS INTERFACE STEPPER MOTOR CONTROLLER**

**SEMICONDUCTOR TECHNICAL DATA**

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751G
(SO–16L)

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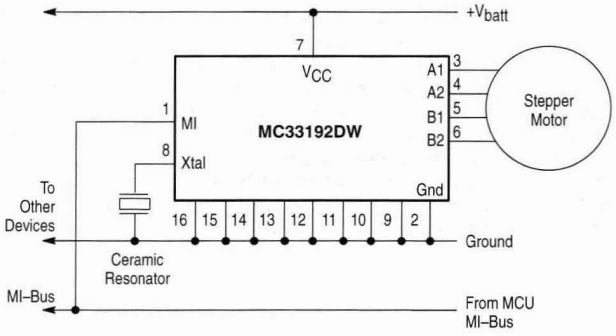
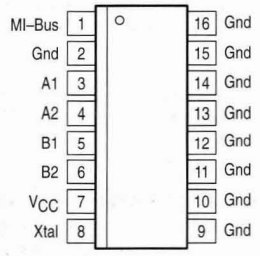
**Simplified Application**




This device contains 1,528 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33192DW | $T_A$ = – 40° to +100°C | SO–16L |

**MAXIMUM RATINGS** (All voltages are with respect to ground, unless otherwise noted.)

| Rating | Symbol | Value | Limit |
|---|---|---|---|
| Power Supply Voltage<br>Continuous Operation<br>Transient Survival (Note 1) | <br>$V_{CC}$<br>$V_{LD}$ | <br>25<br>40 | V |
| Digital Input Voltage | $V_i$ | 0.3 to $V_{CC}$ + 0.3 | V |
| Output Current ($T_A$ = – 40°C) | $I_{OLT}$ | 260 | mA |
| Output Current ($T_A$ = 100°C) | $I_{OHT}$ | 150 | mA |
| Storage Temperature | $T_{stg}$ | – 40 to +150 | °C |
| Operating Temperature (Note 2) | $T_A$ | – 40 to +125 | °C |
| Junction Temperature | $T_J$ | – 40 to +150 | °C |
| Power Dissipation ($T_A$ = 100°C) | $P_D$ | 0.5 | W |
| Load Dump Transient (Note 3) | $V_{LD}$ | 40 | V |

**DC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{CC}$ ≤ 15.5 V, – 40°C ≤ $T_A$ ≤ 100°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Standby Current ($V_{CC}$ = 15.5 V) (Note 4) | $I_Q$ | – | – | 12 | mA |
| Output Current ($V_{CC}$ = 15.5 V) | $I_O$ | – | 120 | – | mA |
| H–Bridge Saturation Voltage ($I_O$ = 150 mA) (Note 5)<br>$T_A$ = – 40°C<br>$T_A$ = 25°C<br>$T_A$ = 100°C | $V_{O(sat)}$ | –<br>–<br>–<br>– | –<br>1.3<br>1.2<br>1.1 | –<br>1.6<br>1.6<br>1.6 | V |
| Address Programming Current ($T_A$ = 25°C) (Note 6) | $I_{pc}$ | – | 1.2 | – | A |

**CONTROL LOGIC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions 9.0 V ≤ $V_{CC}$ ≤ 15.5 V, – 40°C ≤ $T_A$ ≤ 100°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Oscillator (Note 7) | $f_{cl}$ | | 640 | – | kHz |
| Message Time Slot ($V_{CC}$ = 12 V) (Note 8) | $t_s$ | 24.8 | 25 | 25.2 | µs |
| Urgent Output Disable ($V_{CC}$ = 12 V) (Note 9) | $t_{od}$ | 9 x $t_s$ | – | – | µs |
| Internal MI–Bus Pull–Up Resistor | $R_{pu}$ | 6.0 | – | 20 | kΩ |
| Internal MI–Bus Zener Diode Clamp Voltage | $V_{cl}$ | – | 18 | – | V |
| Address Programming Voltage (Note 10) | $V_p$ | 10 | 12 | 14 | V |
| Program Energize Time | $t_{ppw}$ | 200 | | 1000 | µs |
| MI–Bus Slew Rate | $\Delta V/\Delta t$ | 1.0 | 1.5 | 2.0 | V/µs |
| MI–Bus "0" Level Input Voltage Threshold | $V_{il}$ | – | – | 1.3 | V |
| MI–Bus "1" Level Input Voltage Threshold | $V_{ih}$ | 2.4 | – | – | V |
| MI–Bus "0" Level Output Voltage ($I_O$ = 30 mA) | $V_{OL}$ | – | – | 1.0 | V |
| Power–On Reset Time ($V_{CC}$ ≥ 7.5 V) | $t_{por}$ | – | 250 | – | µs |

**NOTES:** 1. Transient capability is defined as the positive overvoltage transient with 250 ms decay time constant. The detection on an overvoltage condition causes all H–Bridges to be latched "off".
2. Ambient temperature is given as a convience; Maximum junction temperature is the limiting factor.
3. Load Dump is the inductive transient voltage imposed on an automotive battery line as a result of opening the battery connection while the alternator system is producing charge current. The detection on an overvoltage condition causes all H–Bridges to be latched "off".
4. Standby Current is with both H–Bridges "off" (Inh1 = Inh2 = 0).
5. H–Bridge Saturation Voltage is referenced to the positive supply or ground respective of the H–Bridge output being High or Low. Saturation voltage is the voltage drop from the output to the positive supply (with output High) and the voltage drop to ground (with output Low).
6. Address Programming Current is the current encountered when the bus is at 12 V during address programming.
7. A typical application uses an external ceramic resonator crystal having a frequency of 644 kHz. An internal capacitor in parallel with ceramic resonator is used to shift the frequency to the working frequency of 640 kHz. The frequency accuracy of the oscillator is dependant on the capacitor and ceramic resonator tolerance (usually ±1.0%).
8. The Message Time Slot is the time required for one complete device message transfer. The message time is equivalent to a total of 16 periods of the oscillator frequency used.
9. If the MI–Bus becomes shorted to ground, all MC33192 outputs will be disabled after a period of nine time slots ($9t_s$).
10. MI–Bus voltage required for address programming.

## GENERAL DESCRIPTION

The MC33192 is a serial stepper motor controller for use in harsh automotive applications using multiplex wiring. The MC33192 provides all the necessary four phase drive signals to control two phase bipolar stepper motors operated in either half or full step modes. Multiple stepper motor controllers can be operated on a real time basis at step frequencies up to 200 Hz using a single microcontroller (MCU). A primary attribute of operation is the utilization of the MI–Bus message media to provide high noise immunity communication ensuring very high operating reliability of motor stepping.

The MC33192 is designed to drive bipolar stepper motors having a winding resistance of 80 Ω at 20°C with a supply voltage of 12 V. It is supplied in a SO–16L plastic package having eight pins, on one side, connected directly to the lead frame thus enhancing the thermal performance to allow a power dissipation of 0.5 W at 120°C ambient temperature.

### Multiple Simultaneous Motor Operation

Several motors can be controlled in a serial fashion, one after the other, using the same software time base. The time base determines the step frequency of the motors. A single motor can be operated at a maximum speed of 200 Hz pull–in with a duration of 5.0 ms per step. Three motors can be operated simultaneously using a 68HC05B6 MCU at the same time base (200 Hz) with about 1.7 ms per step. A 68HC11 MCU can control 4 stepper motors with adequate program step time. The step frequency must be decreased to control additional motors. To control eight motors simultaneously would require the motor speed to be decreased to 100 Hz producing about 2.0 ms time duration per step with adequate program time.

### MI–Bus General Description

The Motorola Interconnect Bus (MI–Bus) is a serial push–pull communications protocol which efficiently supports distributed real time control while exhibiting a high level of noise immunity.

Under the SAE Vehicle Network categories, the MI–Bus is a Class A bus with a data stream transfer bit rate in excess of 20 kHz and thus inaudible to the human ear. It requires a single wire to carry the control data between the master MCU and its slave devices. The bus can be operated at lengths up to 15 meters.

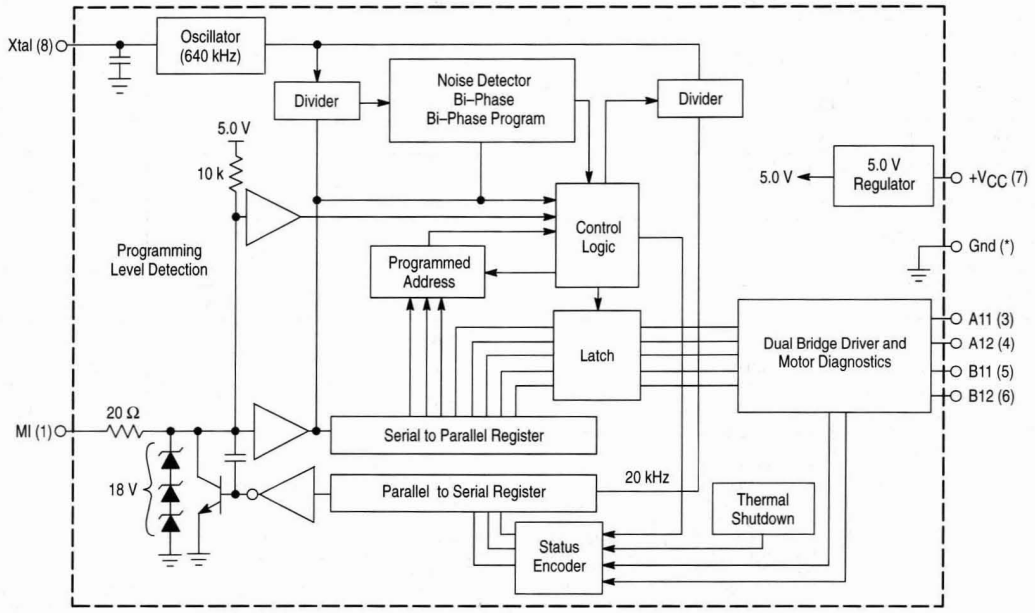
At 20 kHz the time slot used to construct the message (25 μs) can be handled by software using many MCUs available on the market.

The MI–Bus is suitable for medium speed networks requiring very low cost multiplex wiring. Aside from ground, the MI–Bus requires only one signal wire connecting the MCU to multiple slave MC33192 devices with individual control.

A single MI–Bus can accomplish simultaneous automotive system control of Air Conditioning, Head Lamp Levellers, Window Lifts, Sensors, Intelligent Coil Drivers, etc. The MI–Bus has been found to be cost effective in vehicle body electronics by replacing the conventional wiring harness.

Figure 1 shows the internal block diagram of the MC33192 Stepper Motor Controller.

**Figure 1. MC33192 Stepper Motor Conroller Block Diagram**




**NOTE:** (*) Pins 2, 9, 10, 11, 12, 13, 14, 15 and 16 are common electrical and heatsink ground pins for the device.

### MI–Bus Access Method

The information on the MI–Bus is sent in a fixed message frame format (See Figure 4). The system MCU can take control of the MI–Bus at any time with a start bit which violates the law of Manchester Bi–Phase code by having three consecutive Time Slots ($3t_S$) held constantly at a Logic "0" state.

### Push–Pull Communication Sequence

Communication between the system MCU and slave MC33192 devices always use the same message frame organization. The MCU first sends eight serial data bits over the MI–Bus comprised of five control bits followed by three address bits. This communication sequence is called a "Push Field" since it represents command information sent from the MCU. The sequence of the five control data bits follow the order D0, D1, D2, D3 and D4. The three address bits are sent in sequential order A0, A1 and A2 defining a binary address code. The condition of MI–Bus during any of the control bit time windows defines a specific control function as shown in Figure 2. A "Pull Sync" bit is sent at the end of the Push Field, the positive edge of which causes all data sent to the selected device to be latched into the output circuit.

**Figure 2. Push Field Data Bits**

| Bit | Name | Control Function |
|---|---|---|
| D4 | Inh2 | Inhibits H–Bridge 2 |
| D3 | Dir2 | Establishes Direction of H–Bridge 2 Current |
| D2 | E | Energizes Bridge Coils 1 and 2 |
| D1 | Dir1 | Establishes Direction of H–Bridge 1 Current |
| D0 | Inh1 | Inhibits H–Bridge 1 |

After the Pull Sync bit is sent, following the Push Field, the MCU listens on the MI–Bus for serial data bits sent back from the previously addressed MC33192 device. This portion of the communication sequence starts the "Pull Field Data" since it represents information pulled from the addressed MC33192 and received by the MCU.

The address selected MC33192 device sends data, in the form of status bits, back to the MCU reporting the devices condition. At the end of the Push Field the MCU outputs a Pull Sync bit which signals the start of the Pull Field. In the Pull Field are three bits (S2, S1 and S0) which report the status of the previously addressed MC33192 according to Figure 3.

**Figure 3. Pull Field Status Bits**

| S2 | S1 | S0 | Status | Comments |
|---|---|---|---|---|
| 0 | 0 | 0 | Not used | |
| 0 | 0 | 1 | Free | |
| 0 | 1 | 0 | No Back EMF | Drivers and/or coils failed |
| 0 | 1 | 1 | Free | |
| 1 | 0 | 0 | Normal/OK | |
| 1 | 0 | 1 | Thermal | Chip temperature > 150°C |
| 1 | 1 | 0 | Programming | PROM energized |
| 1 | 1 | 1 | Selection failed | Noise on MI–Bus, failed or disconnected module |

The positive edge of the Pull Sync pulse (set by the MCU) causes all Push Field Data sent to the selected MC33192 to be stored in the output latch circuit in time with the strobe pulse. This means the data bits are emitted in real time synchronization with the MCU's machine cycle. The strobe pulse occurs only after the Push Field sequence is validated by the address selected device.

### Message Validation

The communication between the MCU and the selected MC33192 device is valid only when the MCU reads (receives) the Pull Field Data having the correct codes (excluding the code "1–1–1" and "0–0–0") followed by an End–of–Frame signal. The frequency of the End–of–Frame signal may be a sub–multiple of the selected devices local oscillator or related to an internal or external analog parameter using a Voltage to Frequency Converter.

### Error Detection

An error is detected when the Pull Field contains the code "1–1–1" followed by the End–of–Frame permanently tied to a logic "1" state (internally from 5.0 V through a pull–up resistor). This means the communication between the MCU and the selected device was not obtained.

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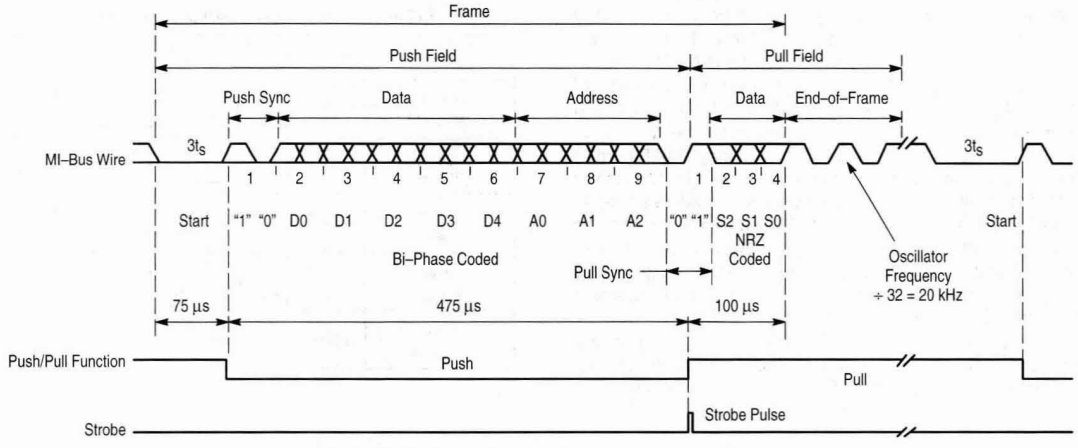
**Figure 4. MI–Bus Timing Diagram**



There are four types of system error detections which are not mutually exclusive; These are:

1) Noise Detection

The system MC33192 slave devices receive the Push Field message from the MCU twice for each Time Slot ($t_S$) of the Bi–Phase Code. A receive error occurs when the two message samples fail to "logic wise" match. Noise and Bi–Phase detection are discussed further under Message Coding.

2) Bi–Phase Detection

The system slave devices receiving the Push Field message from the MCU detect the Bi–Phase Code. A detector error occurs when the two time slots of the Bi–Phase Code do not contain an Exclusive–OR logic function.

3) Field Check

A field error is detected when a fixed–form bit field contains an improper number of bits. A bit error can also be detected by the MCU during the Push Field. The MCU can simultaneously monitor the MI–Bus at the time it is sending data. A bit error is detected if the sent bit value does not match the value which was monitored.

4) Urgent Output Disable

If the MI–Bus becomes shorted to ground, the slave device outputs will be disabled after a period of $9t_S$. The MCU itself can take advantage of this feature to "globally" disable the outputs of all system slave devices by keeping the MI–Bus at a logic "0" level for a duration of $9t_S$ or more. Normal operation is resumed when the MCU sends a "standard" instruction over the MI–Bus.

**Basic Stepper Motor Construction and Operation**

Stepper motors are constructed with a permanent magnet rotor magnetized with the same number of pole pairs as contained in one stator coil section. Operationally, stepper motors rotate at constant incremental angles by stepping one step every time the current switches discretely in one stator field coil causing the North–South stator field to rotate either clockwise or counter–clockwise causing the permanent magnet rotor to follow (see Figure 5). For simplicity, assume the starting condition of the A1 to A2 stator field to be top to bottom polarized N to S and the B1 to B2 stator field to be left to right polarized N to S. The resulting stator field will produce a vector which points in the direction of position 3. The rotor will, in this case, be in the position shown in Figure 5 (pointing to position 1). This initial condition corresponds to that of step 1 in Figure 6. As the direction of current flow in the B1 to B2 stator field is reversed, the field polarity of the B1 to B2 also reverses and is left to right polarized S to N. This causes the resulting stator field vector to point in the direction of position 4. This in turn causes the N–S rotor to follow and rotate 90° in a clockwise direction and point in the direction of position 2. This condition corresponds to step 2 of Figure 6. Continued clockwise rotor steps will be experienced as the stator field continues to be incrementally rotated as shown in steps 3, 4, 5, etc. of Figure 6. The 90° steps in this simplistic example constitute "full steps". It is to be noticed that both coils, in the foregoing full step example, were simultaneously energized in one of two directions. It is possible to increment the rotor in 45° "intermediate steps" or "half steps" by alternately energizing only one stator coil at a time in the appropriate direction while turning the other stator coil off. The drive signals for Half Step operation are shown in Figure 7. The Power output stages of the MC33192 consist of two H–Bridges capable of driving two–phase bi–polar permanent magnet motors in either half or full step increment.

**Figure 5. Permanent Magnet Stepper Motor**

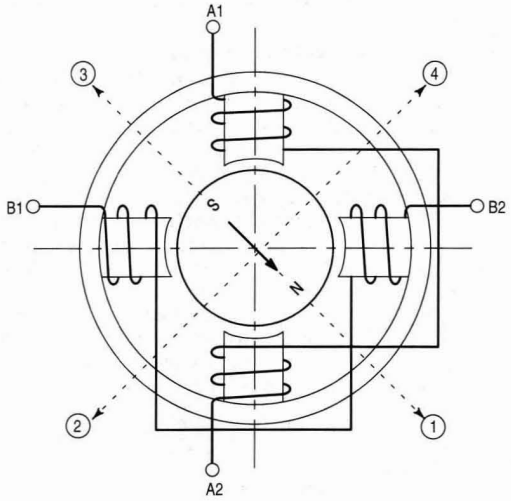



**Figure 6. 4–Step "Full Step" Operation**

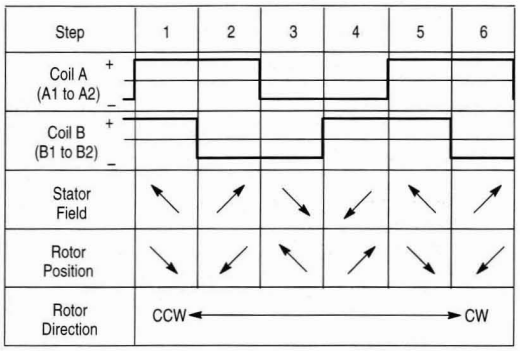
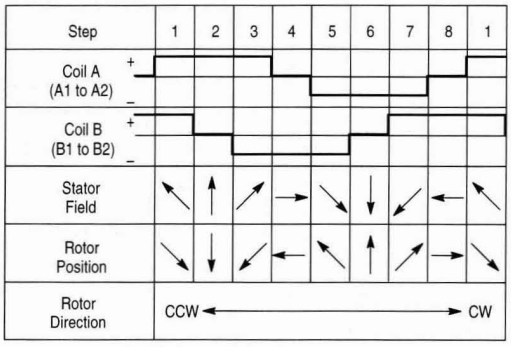



**Figure 7. 8–Step "Half Step" Operation**



Permanent magnetic stepping motors exhibit the characteristic ability to hold a shaft rotor position with or without a stator coil being energized. Normally the shaft holding ability of the motor with a stator coil energized is referred to as "Holding Torque" while "Residual Torque" or "Detent Torque" refers to the shaft holding ability when a stator coil is not energized. The Holding Torque value is dependent on the interactive magnetic force created by the resulting energized stator fields with that of the permanent magnet rotor. The Residual Torque is a function of the physical size and composition of the permanent magnet rotor material coupled with its intrinsic magnetic attraction for the un–energized stator core material and as a result, the weaker of the two torques.

It is to be noted when using half step operation, only one coil is energized during alternate step periods which produces a somewhat weaker Holding Torque. Holding Torque is maximized when both coils are simultaneously energized. In addition, since each winding and resulting flux conditions are not perfectly matched for each half step, incremental accuracy is not as good as when full stepping.

**Two Phase Drive Signals**

The DIR1 and DIR2 bits in the Data Frame of the Push Field determine the direction of H–Bridge current flow, and thus the magnetic field polarization of the stator coils, for H–Bridge outputs "A" and "B" respectively. The directional signals DIR1 and DIR2, generated by the MCU, communicate over the MI–Bus to control the two H–Bridge power output stages of the MC33192 to drive two phase bipolar permanent magnet motors. Figure 8 shows the MC33192 truth table to accomplish incremental stepping of the motor in a clockwise or counter–clockwise direction in either half or full step modes. The stator field polarization and rotor position are also shown for reference relative to the basic stepper motor of Figure 5.

**Figure 8. Truth Table and Serial Push Field Data Bits For Sequential Stepping**

| | | Push Field Bits | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | | D0 | D1 | D2 | D3 | D4 | H–Bridge Outputs | | | | Stator Field (Note 2) | Rotor Position (Note 2) | Direction of Shaft Rotation |
| Full | Half | Inh1 | DIR1 | E | DIR2 | Inh2 | A1 | A2 | B1 | B2 | | | |
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | ↖ | ↘ | CCW ↑ |
| – | 2 | 1 | 0 | 1 | X | 0 | 1 | 0 | Z | Z | ↑ | ↓ | |
| 2 | 3 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | ↗ | ↙ | |
| – | 4 | 0 | X | 1 | 1 | 1 | Z | Z | 0 | 1 | → | ← | |
| 3 | 5 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | ↘ | ↖ | |
| – | 6 | 1 | 1 | 1 | X | 0 | 0 | 1 | 0 | 0 | ↓ | ↑ | |
| 4 | 7 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | ↙ | ↗ | |
| – | 8 | 0 | X | 1 | 0 | 1 | Z | Z | 1 | 0 | ← | → | CW ↓ |
| | | 0 | X | X | X | 0 | Z | Z | Z | Z | | | |
| | | 1 | 1 | 0 | 1 | 1 | Z | 1 | Z | 1 | | | |
| | | 1 | 0 | 0 | 0 | 1 | 1 | Z | 1 | Z | | | |
| | | 1 | 1 | 0 | 0 | 0 | Z | 1 | Z | Z | | | |
| | | 0 | 0 | 0 | 1 | 1 | Z | Z | Z | 1 | | | |

**NOTES:** 1. X = Don't care; Z = High impedance; 1 = High (active "on") state; 0 = Low (inactive "off") state.
2. The stator field direction and position of the rotor are shown for explanation purposes and relative to the basic stepper motor shown in Figure 3.
3. DIR1 establishes the direction of current flow in H–Bridge "A".
4. DIR2 establishes the direction of current flow in H–Bridge "B".

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### MI–Bus Interface Description

The MI–Bus Interface shown in Figure 9 is made up of a single NPN transistor (Q1). The two main functions of this NPN transistor are:

1) To drive the MI–Bus during the Push Field with approximately 20 mA of current while also exhibiting low saturation characteristics ($V_{CE(sat)}$).

2) To protect the Input/Output (I/O) pin of the MCU against any Electro–Magnetic Interference (EMI) captured on the bus wire.

Without the NPN transistor, the MCU could be destroyed as a result of receiving excessive EMI energy present on the bus. In addition, the transistor blocks the MCU from receiving EMI signals which could erroneously change the data direction register of the MCU I/O.

The MCU input pin ($P_{in}$), used to read the Pull Field of the MI–Bus, is protected by two diodes (D2 and D3) and two resistors (R5 and R6). Any transient EMI generated voltage present on the bus is clamped by the two diodes to a windowed voltage value not to be greater than the $V_{DD}$ or less than the $V_{SS}$ supply voltages of the MCU.

### MI–Bus Levels

The MI–Bus can have one of two valid logic states, recessive or dominant. The recessive state corresponds to a Logic "1" and is obtained through use of a 10 kΩ pull–up resistor (R9) to 5.0 V. The dominant state corresponds to a Logic "0" which represents a voltage less than 0.3 V and created by the $V_{CE(sat)}$ of Q1.

### MI–Bus Overvoltage Protection

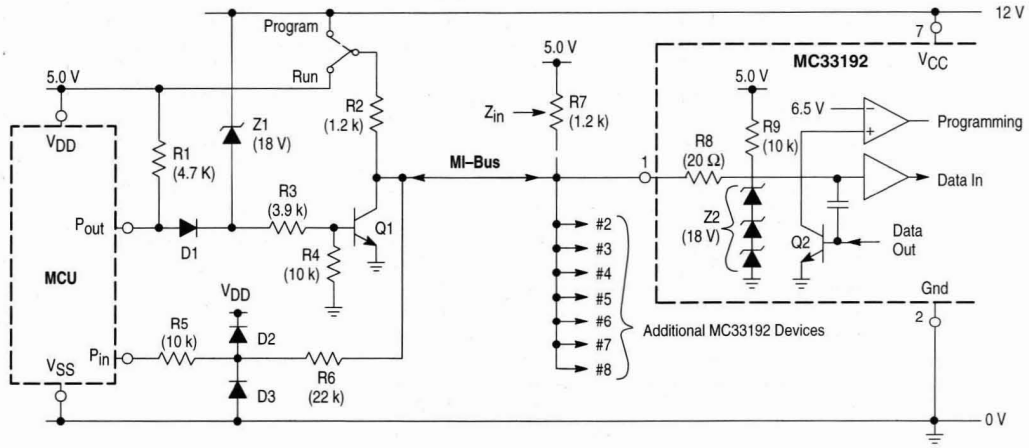
An external zener diode (Z1) is incorporated in the interface circuit so as to protect the MCU output pin ($P_{out}$) from overvoltages commonly encountered in automotive applications as a result of "Load Dump" and "Jump Start" conditions. Load Dump is defined as the inductive transient generated on the battery line as a result of opening the battery connection while the alternator system is producing charge current. Jump Start overvoltages are the result of paralleling the installed automotive battery, through the use of "jumper cables", to an external voltage source in excess of the vehicles nominal system voltage. For 12 V automotive systems, it is common for 24 V "jump start" voltages to be used.

When an overvoltage situation (>18 V) exists, due to a load dump or jump start condition, the zener diode (Z1) is activated and supplies base current to turn on the NPN transistor Q1 causing the bus to be pulled to less than 0.3 V producing a Logic "0" on the MI–Bus. After a duration corresponding to $8t_S$ (200 μs) of continuous Logic "0" on the bus all MC33192 devices will disable their outputs. Normal operation is resumed, following the overvoltage, by the MCU sending out a "standard" message instruction.

### MI–Bus Termination Network

The MI–Bus is resistively loaded according to the number of MC33192 devices installed on the bus. Each MC33192 has an internal 10 kΩ pull–up resistor to 5.0 V. An external pull–up resistor (R7) is recommended to be used to optimally adjust termination of the bus for a load resistance of 600 Ω.

**Figure 9. MI–Bus MCU Interface**



## MESSAGE CODING

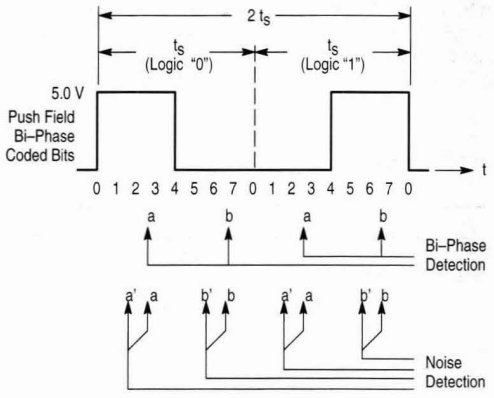
### Bi–Phase Coding and Detection

The Manchester Bi–Phase code shown in Figure 10 requires two time slots ($2t_S$) to encode a single data bit. This allows detection of a single error at the time slot level. The logic levels "1" or "0" are determined by the organization of the two time slots. These always have complementary logic levels of either zero volts or plus five volts, which are detected using an Exclusive OR detection circuit during the Push Field sequence. A "1" bit is detected when the first time slot is set to a zero logic state (0 V) followed by the second time slot set to a logic state one (5.0 V). Conversely, a "0" bit is detected when the first time slot is set to the logic state "one" (5.0 V) followed by a second time slot set to a "zero" logic state (0 V). For these two bits are Exclusive–ORs of each other.

The addressed devices receiving the Push Field detect the Bi–Phase code. Bi–Phase detection involves the sampling of the Push Field Bi–Phase code twice (a and b) for each time slot. A code error occurs when the two time slots of the Bi–Phase do not follow a logical Exclusive–OR function (see Figure 10).

Noise monitoring is accomplished by sampling the Push Field Bi–Phase code twice (a and a') and (b and b') during each time slot. A noise error is detected if the two sample values do not have the same logical level.

**Figure 10. Noise/Bi–Phase Detection**


2 tS
tS (Logic "0")
tS (Logic "1")
5.0 V
Push Field Bi–Phase Coded Bits
t
0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0
a b a b
Bi–Phase Detection
a' a b' b a' a b' b
Noise Detection

Each message frame consists of two fields: The Push Field, in which data and addresses are transferred by the MCU to the slave device; and the Pull Field, in which serial data is transferred back to the MCU from the address selected slave device. The message frame is broken down into seven individual field segments as indicated in Figure 4 (Start, Push Field Sync, Push Field Data, Push Field Address, Pull Field Sync, Pull Field Data, and End–of–Frame). The following lists the bit size and function of each of these segments:

1) **Start** is the start of message and consists of three time slots ($3t_S$) having the dominant Logic "0" state of less than 0.3 V. Holding the MI–Bus at ground for three time slots ($3t_S$) marks the beginning of the message frame by violating the law of the Manchester Code.

2) **Push Field Sync** is a single bit which establishes initial timing for the Push Field Data to follow.

3) **Push Field Data** is comprised of five serial data bit fields (D0, D1, D2, D3 and D4) which comprise the instruction set defining the configuration and condition of the two H–Bridge output stages.

4) **Push Field Address** is comprised of three serial data bit fields (A0, A1 and A2) which define the address or name of a MC33192 on the MI–Bus.

5) **Pull Field Sync** is a single bit which establishes the end of the Push Field and the initial start timing for the Pull Field Data to follow.

6) **Pull Field Data** is made up of three serial data bit fields (S2, S1 and S0) which contain the existing status information of an addressed MC33192.

7) **End–of–Frame** field is a signal which communicates to the MCU that the status information sent by the MC33192 is complete.

The Push Field Sync bit, Push Field Data bits, Push Field Address bits, Pull Field Sync bit are all coded by the Manchester Bi–Phase L Code. The Pull Field Data bits are Non–Return to Zero (NRZ) coded. The End–of Frame field is a square wave signal with a frequency of 20 kHz or higher so as to avoid a condition which causes a bus violation.

The Manchester Bi–Phase L code requires two time slots ($2t_S$) to encode a single bit. This allows a single error to be detected during the time slot.

**Address Programming** involves the use of three instructions. Refer to Figure10.

**First Instruction** Set the MI–Bus continuously at 12 V. This places the MC33192 in the programming mode. Programming is possible only when the MI–Bus is at 12 V.

Next, the MCU serially enters "Logic Zeros" in all five Push Field Data bit positions (D0, D1, D2, D3 and D4) followed by the designated address value in the Push Field Address positions (A0, A1, & A2).

The MCU now waits 275 µs before starting the second instruction. The total of the Pull time, Delay time, and Bus Violation time (V) of the second instruction (150 µs, 275 µs and 75 µs respectively) will cause the memory cell to be energized for 500 µs. During the first 150 µs of this time, the MCU is checking the Pull Field Data Bits S2, S1 and S0 looking for the **programming code "110"** to indicate complete activation of the memory cell.

**Second Instruction** (MI–Bus voltage remaining at 12 V)

The MCU repeats the same Push Field instruction as previously sent in the First Instruction; entering all "Logic Zeros" in the Push Field Data positions followed by the designated Push Field Address value in the address positions.

Again, the MCU waits for the Pull, Delay, and Bus violation time while checking the Pull Field Data bits looking for the **programming code "110"** code. The MCU must repeat the initial Push Field Address instruction until a "110" code is received before advancing to the Third Instruction.

**Third Instruction** The MI–Bus voltage is lowered to 5.0 V.

The MCU serially loads "Logic Zeros" in all five Push Field Data bit positions followed by the programmed address in the Push Field Address positions. The MCU then checks the Pull Field Address status bits looking this time for the

10

**programming OK code "100"** indicating the address programming to be executed.

The First and Second Instructions must be repeated until the MCU successfully receives the programming code "100". Address programming is not complete until a "100" OK status is received by the MCU with the MI–Bus voltage at 5.0 V.

**Overwrite–Bit Programming** involves the use of two instructions. See Figure 11.

**First Instruction** Have the MI–Bus continuously set at 12 V so as to have the MC33192 in the programming mode. Programming can only be accomplished with the MI–Bus at 12 V.

The MCU serially enters "Logic Zeros" for the Push Field Data bits D0, D1, D2 and D3 and a Logic "1" for D4 bit followed by the programmed address bits A0, A1 and A2.

The MCU now waits 275 µs before starting the second instruction. The total of the Pull time, Delay time, and Bus Violation time (V) of the second instruction (150 µs, 275 µs and 75 µs respectively) will cause the memory cell to be energized for 500 µs. During the first 150 µs of this time, the MCU is checking the Pull Field Data Bits for the status of bits S2, S1 and S0 looking for the **programming code "110"** to indicate complete activation of the memory cell.

**Second Instruction** (MI–Bus remaining at 12 V)

The MCU repeats the first instruction outlined above until the **programming OK code "100"** is sent back to the MCU from the selected MC33192 indicating the overwrite–bit protection to be programmed. If after eight repeat instructions, the programming code "110" or the OK code "100" is not generated four times in succession, programming of the MC33192 has failed. If this occurs, the Overwrite–Bit Programming sequence should be reviewed and re–started from the beginning.

### H–Bridge Output

The H–Bridge output drive circuit and associated diagnostic encoder are shown in Figure 12. The H–Bridge output uses internal diode clamps (D1, D2, D3, D4) to provide transient protection of the output transistors necessary when switching inductive loads associated with stepper motors.

### Back EMF Detection

Three different Back EMF currents can occur depending on whether the motor is running or manner in which it is being stopped. Referring to Figure 12; When the Dir1 bit is set to logic 0, the direction of current flow will be from $V_{CC}$ through transistor Q2, Coil A (A1 to A2), and transistor Q4 to ground.

1) **Fast Decay** (when transistors Q1, Q2, Q3 and Q4 are switched off).

When the current flowing in the coil is stopped by setting the $\overline{Inh1}$ bit to logic 0, the back EMF current will circulate through the voltage supply ($V_{CC}$) and diodes D1 and D3. At that time, the voltage developed across the diode D1 is detected by transistor Q6. The generated voltage pulse of Q6 is then encoded and sent, in the Pull–Field, to the microprocessor.

2) **Slow Decay** (Q3 and Q4 are switched off)

When the current flowing in the coil is stopped by setting the E bit to logic 0, the back EMF current will circulate through the diode D1 and transistor Q2 which is already switched on.

3) **When Motor is Running**

The rotational direction of the motor changes whenever the Dir bit state is changed. When the Dir bit is changed from a logic 0 to a logic 1, transistors Q2 and Q4 are switched off and transistors Q1 and Q3 are switched on. At this time, the back EMF current will circulate from ground through diodes D1 and D3 to the voltage supply ($V_{CC}$). In all cases, the back EMF currents will be detected by transistors Q5 and Q6.

**Figure 11. Address Programming Diagram**

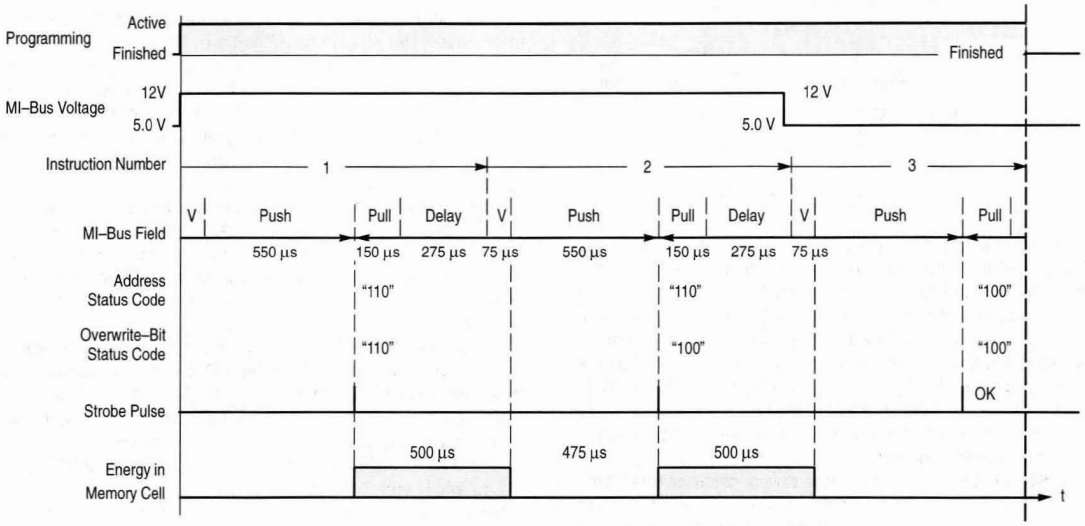
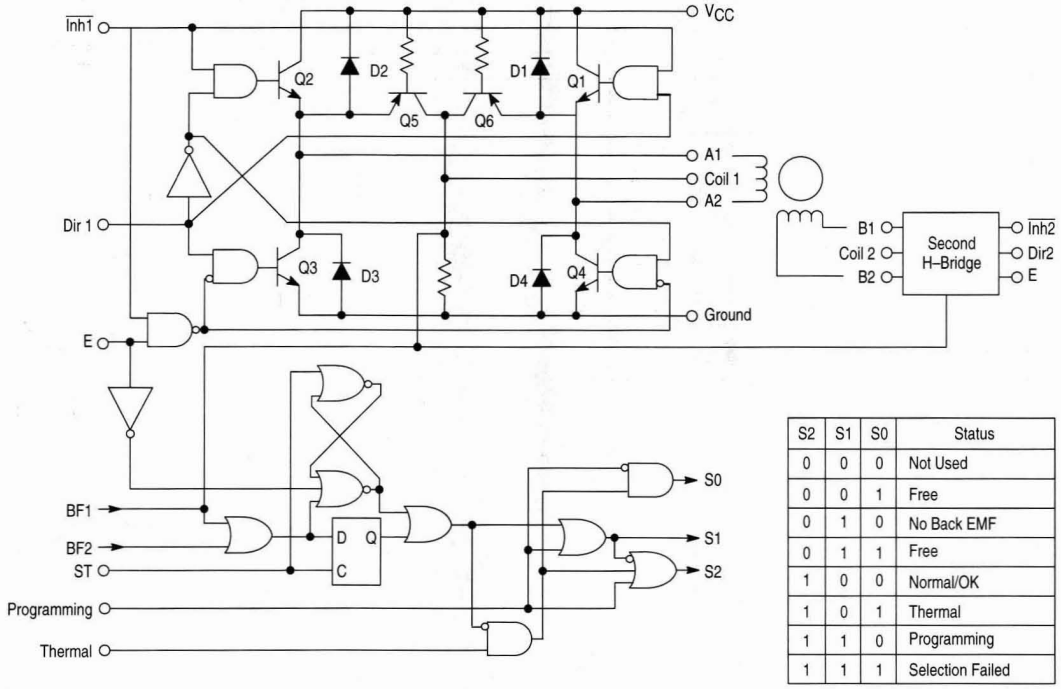


**Figure 12. H–Bridge Output Drive Circuit and Diagnostic Encoder**




| S2 | S1 | S0 | Status |
|---|---|---|---|
| 0 | 0 | 0 | Not Used |
| 0 | 0 | 1 | Free |
| 0 | 1 | 0 | No Back EMF |
| 0 | 1 | 1 | Free |
| 1 | 0 | 0 | Normal/OK |
| 1 | 0 | 1 | Thermal |
| 1 | 1 | 0 | Programming |
| 1 | 1 | 1 | Selection Failed |

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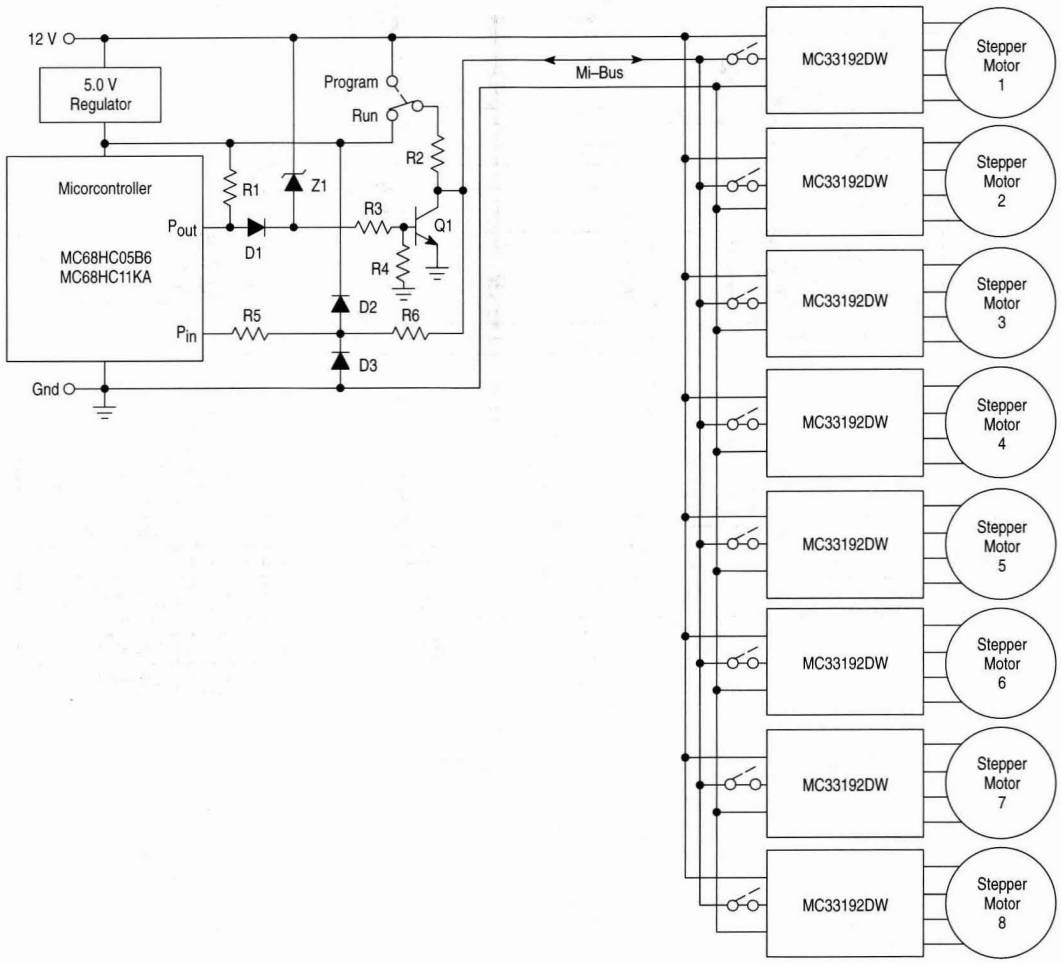
**Figure 13. Single Wire MI–Bus Control of 8 Stepper Motors**

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MOTOROLA

# MC33193

*Advance Information*

## Automotive Direction Indicator

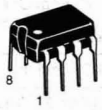
**AUTOMOTIVE DIRECTION INDICATOR**

**SEMICONDUCTOR TECHNICAL DATA**

The MC33193 is a new generation industry standard UAA1041 "Flasher". It has been developed for enhanced EMI sensitivity, system reliability, and improved wiring simplification. The MC33193 is pin compatible with the UAA1041 and UAA1041B in the standard application configuration as shown in Figure 9, without lamp short circuit detection and using a 20 mΩ shunt resistor. The MC33193 has a standby mode of operation requiring very low standby supply current and can be directly connected to the vehicle's battery. It includes an RF filter on the Fault detection pin (Pin 7) for EMI purposes. Fault detection thresholds are reduced relative to those of the UAA1041, allowing a lower shunt resistance value (20 mΩ) to be used.

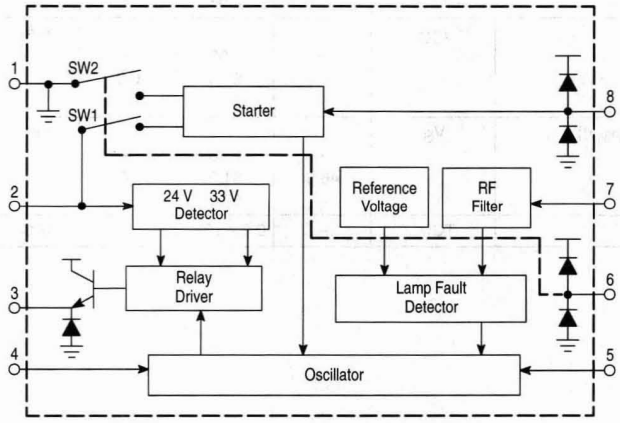
- Pin Compatible with the UAA1041
- Defective Lamp Detection Threshold
- RF Filter for EMI Purposes
- Load Dump Protection
- Double Battery Capability for Jump Start Protection
- Internal Free Wheeling Diode Protection
- Low Standby Current Mode

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)



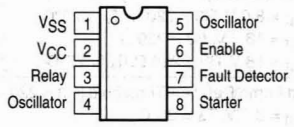

**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**Simplified Block Diagram**




This device contains 60 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33193D | $T_A$ = –40° to +125°C | SO–8 |
| MC33193P | | DIP–8 |

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**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Pin 1 Positive Current (Continuous/Pulse) | I1+ | 150 to 500 | mA |
| Pin 1 Negative Current (Continuous/Pulse) | I1– | –35 to –500 | mA |
| Pin 2 Current (Continuous/Pulse) | I2 | ±350 to ±1900 | mA |
| Pin 3 Current (Continuous/Pulse) | I3 | ±300 to ±1400 | mA |
| Pin 8 Current (Continuous/Pulse) | I8 | ±25 to ±50 | mA |
| ESD (All Pins Except Pin 4 for Negative Pulse) | $V_{ESD}$ | ±2000 | V |
| ESD (Pin 4 Negative Pulse) | $V_{ESD4-}$ | –1000 | V |
| Junction Temperature | $T_J$ | 150 | °C |
| Operation Ambient Temperature Range | $T_A$ | –40 to +125 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($-40°C \le T_A \le +125°C$, $8.0\ V \le V_{CC} \le 18\ V$, unless otherwise noted. Typical values reflect approximate mean at $T_A = 25°C$, $V_{CC} = 14\ V$ at the time of initial device characterization.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Battery Voltage Range (Normal Operation) | $V_b$ | 8.0 | – | 18 | V |
| Overvoltage Detector Threshold ($V_{Pin2} - V_{Pin1}$) | $V_{ih}$ | 19 | 20.2 | 22 | V |
| Clamping Voltage (R2 = 220 Ω) | $V_{cl}$ | 27 | 29.2 | 34 | V |
| Output Voltage [I = –250 mA ($V_{Pin2} - V_{Pin3}$)] | $V_{sat}$ | – | – | 1.5 | V |
| Starter Resistance ($R_{st} = R2 + R_{Lamp}$) | $R_{st}$ | – | 3.3 | 3.6 | kΩ |
| Oscillator Constant (Normal Operation, $T_A = 25°C$) | $K_n$ | 1.3 | 1.5 | 1.75 | X |
| Temperature Coefficient of $K_n$ | $TC_{Kn}$ | – | 0.001 | – | 1/°C |
| Duty Cycle (Normal Operation) | – | 45 | 50 | 55 | % |
| Oscillator Constant (One 21 W Lamp Defect, $T_A = 25°C$) | $K_f$ | 0.63 | 0.68 | 0.73 | X |
| Duty Cycle (One 21 W Lamp Defect) | – | 35 | 40 | 45 | % |
| Oscillator Constant ($T_A = 25°C$) | K1<br>K2 | 0.167<br>0.250 | 0.180<br>0.270 | 0.193<br>0.290 | – |
| Standby Current (Ignition "Off") | $I_{CC}$ | – | 2.0 | 100 | μA |
| Current Consumption (Relay "Off," Enable Pin 6 High)<br>$V_{bat}$ = 8.0 V, R3 = 220 Ω, $T_A = 25°C$<br>$V_{bat}$ = 13.5 V, R3 = 220 Ω<br>$V_{bat}$ = 18 V, R3 = 220 Ω, $T_A = 25°C$ | $I_{CC}$ | <br>–<br>–<br>– | <br>1.40<br>2.16<br>2.64 | <br>–<br>3.5<br>– | mA |
| Current Consumption (Relay "On")<br>$V_{bat}$ = 8.0 V, R3 = 220 Ω, $T_A = 25°C$<br>$V_{bat}$ = 13.5 V, R3 = 220 Ω<br>$V_{bat}$ = 18 V, R3 = 220 Ω, $T_A = 25°C$ | $I_{CC}$ | <br>–<br>–<br>– | <br>1.62<br>2.06<br>3.30 | <br>–<br>6.0<br>– | mA |
| Defect Lamp Detector Threshold [R3 = 220 Ω, ($V_{Pin2} - V_{Pin7}$)]<br>$V_{bat}$ = 8.0 V, $T_A = 25°C$<br>$V_{bat}$ = 13.5 V<br>$V_{bat}$ = 18 V, $T_A = 25°C$ | $V_S$ | <br>–<br>46.5<br>– | <br>43.6<br>51.0<br>57.0 | <br>–<br>56<br>– | mV |
| Temperature Coefficient of $V_S$ | $TC_{Vs}$ | – | $0.3 \times 10^{-3}$ | – | 1/°C |

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**Figure 1. Normal Operation Oscillator Timing Diagram**

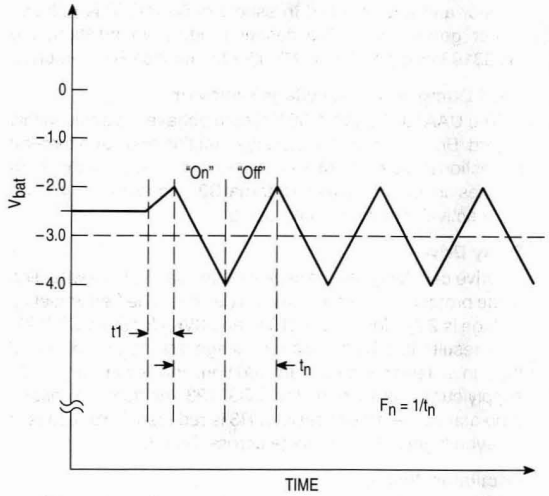
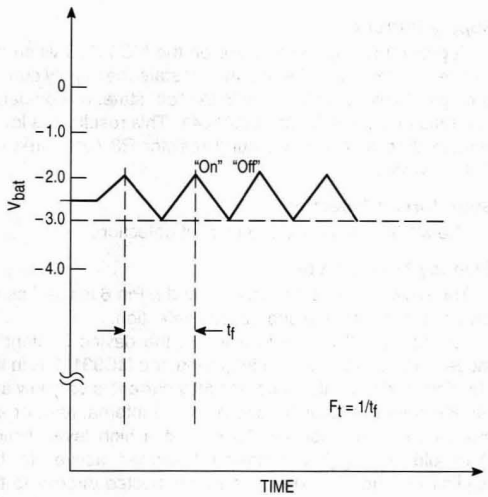



**Figure 2. One Defective Lamp Oscillator Timing Diagram**




## INTRODUCTION

The MC33193 is designed to drive the direction indicator flasher relay. It is a new generation industry standard UAA1041 "Flasher". It consists of the following functions:

- Supply and Protections
- On–Chip Relay Driver
- Oscillator
- Starter Functions
- Lamp Fault Detector with Internal RF Filter
- Standby Mode

### Supply and Protection Systems

Pin 1 is connected to ground via resistor R3 which limits the current in the event of any high voltage transients. Pin 2 ($V_{CC}$) is the positive supply and may be connected directly to the vehicle's battery voltage.

*Overvoltage and Double Battery Protection:* When the applied $V_{CC}$ to $V_{SS}$ voltage is greater than 22 V, the overvoltage detector circuit turns the relay driver off. Both the device and the lamps are protected if two 12 V batteries are connected in series and used to jump start the vehicle.

*Load Dump Overvoltage Protection:* A 29 V overvoltage detector protects the circuits against high voltage transients due to load dumps and other low energy spikes. The relay driver is automatically turned on whenever the $V_{CC}$ to $V_{SS}$ voltage is greater than 34 V.

*Overvoltage Protection, High Voltage Transients:* The Enable and the Starter pins are protected against positive and negative transients by internal on–chip diodes.

### On–Chip Relay Driver

The device directly drives the flasher relay. The output structure is an Emitter of an NPN transistor. It contains the free wheeling diode circuitry necessary to protect the device whenever the relay is switched off.

### Oscillator

The device uses a sawtooth oscillator (Figure 1).

The frequency is determined by the external components C1 and R1. In the normal operating mode, the flashing frequency is: $F_n = 1/R1*C1*K_n$. With a defective (open) 21 W lamp (Figure 2), the flashing frequency changes to: $F_n = 2.2*F_n$.

The typical first flash delay (the time between the moment when the indicator switch is closed and the first lamp flash occurs) is: t1 = K1*R1*C1

The fault detection delay is from the time relay R1 is on and fault detection is enabled. Where a 21 W lamp opens, the delay is expressed as: t2 = K2*R1*C1

### Starter

Pin 8 is connected through a 3.3 kΩ resistor to the flashing lamp. Pin 8 is the input to the Starter function and senses the use of S1 by sensing ground through the lamp (Figures 9 and 10).

### Lamp Fault Detector with Internal RF Filter

A Lamp defect is sensed by the lamp fault detector's monitoring of the voltage developed across the external shunt resistor $R_S$ via the RF filter. The $R_S$ voltage drop is compared to a $V_{bat}$ dependent internal reference voltage ($V_{ref}$) to validate the comparison over the full battery voltage range. A detected fault causes the oscillator to change frequency (Figure 2).

### Standby Mode

When the ignition key and warning switches are open; Enable is in a low state and the internal switches, SW1 and SW2, are open and no current passes through the circuit. In this condition, the device's current consumption is zero ($I_{CC}$ = 0). When ignition key and warning switches are closed; Enable is in a high state with SW1 and SW2 being closed and the circuit is powered on.

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## MAIN DIFFERENCES BETWEEN UAA1041B & MC33193

The MC33193 is pin compatible with the UAA1041.

**Supply Current**

Supply current is more stable on the MC33193 when the device is in "on" or "off" state. In "on" state the supply current is only 40% higher than when in the "off" state, as compared to a ratio of 3 times for the UAA1041. This results in a lower voltage drop across the ground resistor R3 (see On–Chip Relay Driver).

**Short Circuit Detection**

The MC33193 has no short circuit detection.

**Standby Mode (Pin 6)**

The UAA1041 has no standby mode. Pin 6 is used as an Enable/Disable for the short circuit detection.

The MC33193 uses Pin 6 to set the device in standby mode. If Pin 6 is connected to ground, the MC33193 is in the standby mode. In this mode, standby current is very low and Pin 8's starter resistor R2 and a 2.0 kΩ internal resistor are switched off. As soon as Pin 6 is at a high level (typical threshold = $2V_{be}$) the device becomes active. In the application, the MC33193 can be connected directly to the battery and awakened whenever Pin 6 is connected to the vehicle's battery by way of a protection resistor and the ignition key switch.

**Lamp Defect Detection (Pin 7)**

The UAA1041 operates with a 30 mΩ shunt resistor to sense the lamp current. It's lamp defect detection threshold of Pin 7 is typically 85 mV.

The MC33193 is designed to operate with 20 mΩ shunt resistor and at a reduced threshold of 50 mV. This reduces power generation in the flasher module. In addition, the MC33193 incorporates an RF filter to enhance RFI immunity.

**Load Dump and Overvoltage Behavior**

The UAA1041 and MC33193 both behave the same in this regard. Both have double battery detection and lamp turn–off protection in the event of a jump start. During load dump, both devices are protected by an internal 30 V zener diode with the relay activated during a load dump.

**Relay Driver**

Drive capability of both devices is the same. Free wheeling diode protection is internal to both devices. The free wheeling voltage is $2V_{be}$ for the UAA1041 and $3V_{be}$ for the MC33193. This results in a higher clamp voltage across the relay and thus in a faster turn–off. In addition, the lower "on" state supply current is lower on the MC33193 and thus the voltage drop across the ground resistor R3 is reduced. This results in an even higher clamp voltage across the relay.

**Oscillator Phase**

The oscillator phase is opposite on the MC33193 as compared to the UAA1041. The Oscillator voltage is falling during "on" state and rising during "off" state for the MC33193.

**Figure 3. Clamping Voltage versus Temperature**

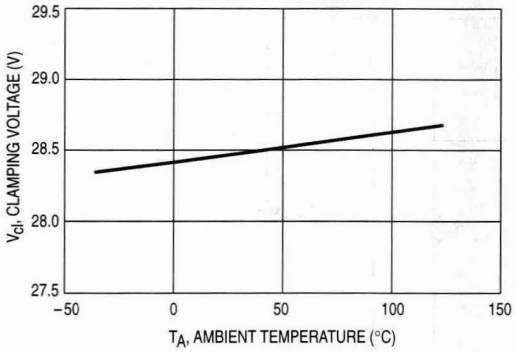


**Figure 4. Overvoltage Detection versus Temperature**

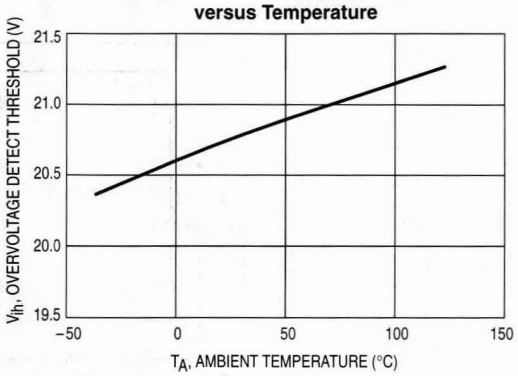


**Figure 5. Supply Current versus Temperature**

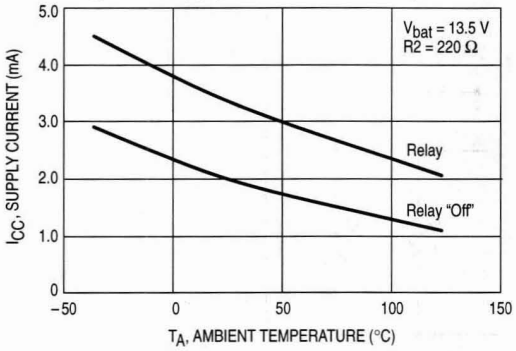


**Figure 6. Output Voltage versus Temperature**

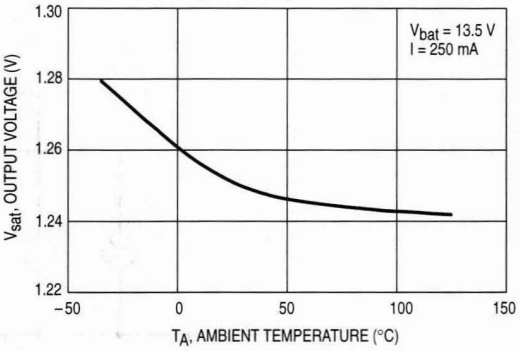


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**Figure 7. Defect Lamp Detection versus Temperature**

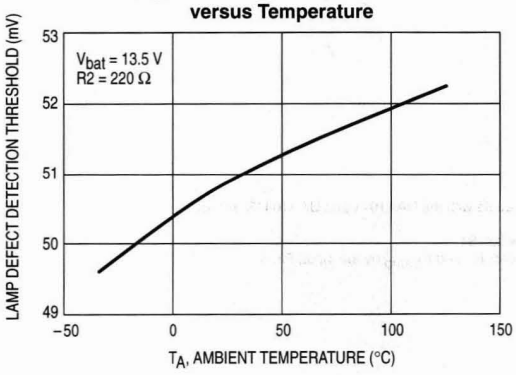



**Figure 8. Oscillator Constant versus Temperature**

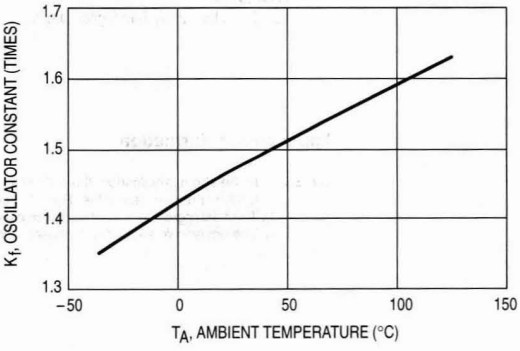
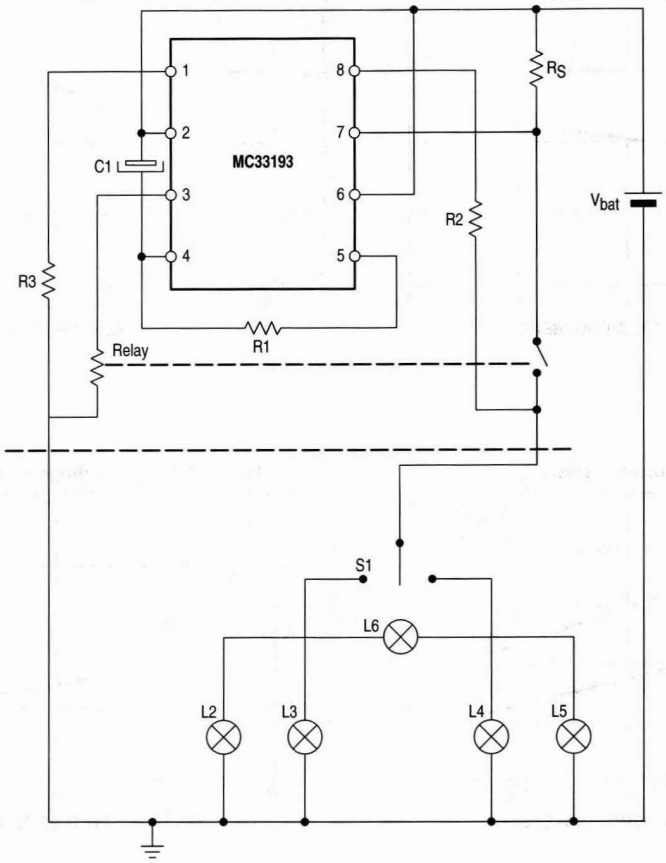


**Figure 9. MC33193 Typical Application**

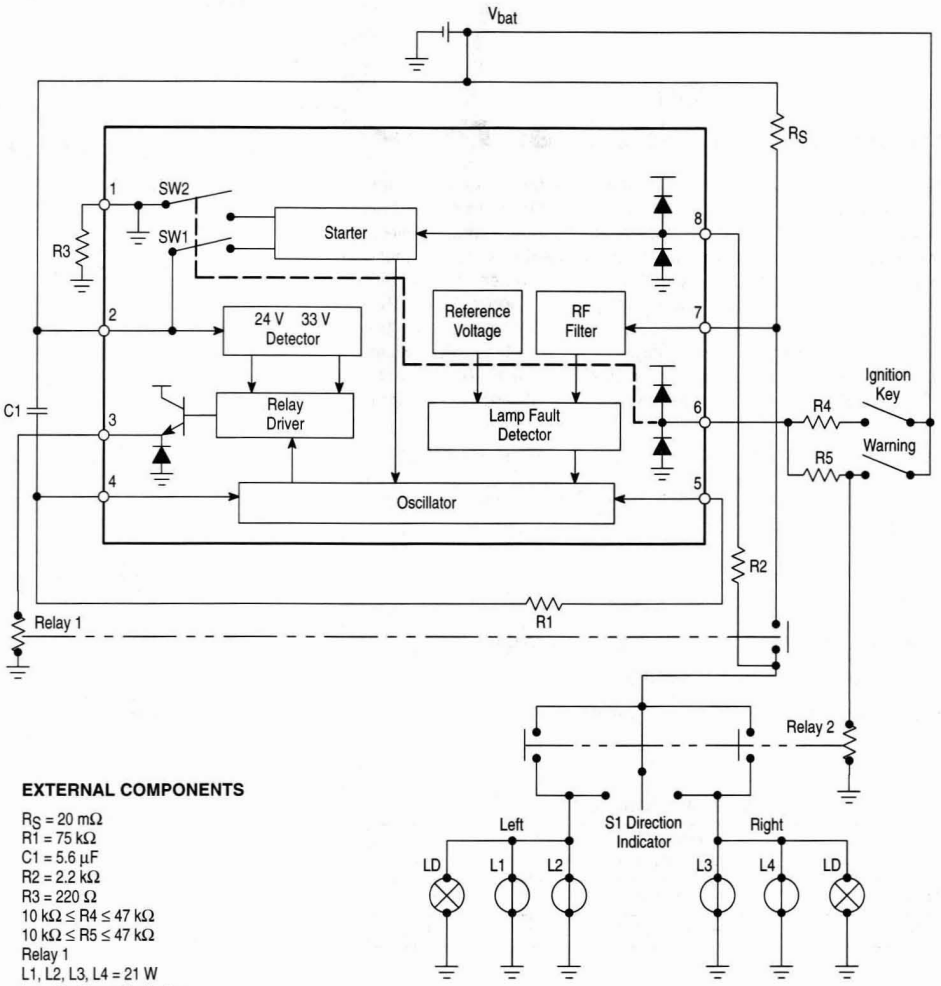



$R_S$ = 20 mΩ
R1 = 75 kΩ
C1 = 5.6 µF
R2 = 3.3 kΩ
R3 = 200 Ω
L2, L3, L4, L5 = 21 W Turn Signal Lamps

## Application Information

**NOTES:** 1. In the above application, the MC33193 is compatible with the UAA1041 and UAA1041B except for the shunt resistor value ($R_S$ = 20 mΩ).
2. The flashing cycle is started by the closing of switch S1.
3. The position of switch S1 is sensed across resistor R2 and $R_{Lamp}$ by the input, Pin 8.

**Figure 10. Typical MC33193 Application**




**EXTERNAL COMPONENTS**

$R_S$ = 20 mΩ
R1 = 75 kΩ
C1 = 5.6 µF
R2 = 2.2 kΩ
R3 = 220 Ω
10 kΩ ≤ R4 ≤ 47 kΩ
10 kΩ ≤ R5 ≤ 47 kΩ
Relay 1
L1, L2, L3, L4 = 21 W
$L_D$ = Dashboard Indicator

## Application Information

**NOTES:** 1. The flashing cycle is started by the closing of switch S1.
2. The S1 switch position is sensed across the resistor R2 and $R_{Lamp}$ by the input (Pin 8).
3. If the logic state at Pin 6 is [0], the current through R2 is off.

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MOTOROLA

# MC33197A

*Advance Information*

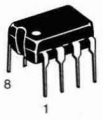
## Automotive Wash Wiper Timer

**AUTOMOTIVE WASH WIPER TIMER**

**SEMICONDUCTOR TECHNICAL DATA**

The MC33197A is a standard wiper timer control device designed for harsh automotive applications. The device can perform the intermittent, after wash, and continuous wiper timer functions. It is designed to directly drive a wiper motor relay. The MC33197A requires very few external components for full system implementation. The intermittent control pin can be switched to ground or $V_{bat}$ to meet a large variety of possible applications. The intermittent timing can be fixed or adjustable via an external resistor. The MC33197A is built using bipolar technology and parametrically specified over the automotive ambient temperature range and 8.0 to 16 V supply voltage. The MC33197A can operate in both front and rear wiper applications.

- Adjustable Time Interval of Less Than 500 ms to More Than 30 s
- Intermittent Control Pin Can Be Switched to Ground or $V_{bat}$
- Adjustable After Wipe Time
- Priority to Continuous Wipe
- Minimum Number of Timing Components
- Integrated Relay Driver With Free Wheeling Protection Diode
- Operating Voltage Range From 8.0 to 16 V
- For Front Wiper and Rear Wiper Window Applications



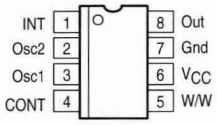

**P SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**ORDERING INFORMATION**

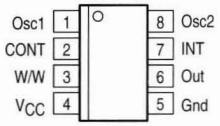
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33197AD | $T_A = -40°$ to +105°C | SO–8 |
| MC33197AP | $T_A = -40°$ to +125°C | DIP–8 |

**PIN CONNECTIONS**




(Top View)

(SO–8)




(Top View)

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Continuous Supply Voltage ($V_{Pin\ 6}$) | $V_{CC}$ | 16 | V |
| Storage Temperature | $T_{stg}$ | –55 to +150 | °C |
| Thermal Resistance (Junction–to–Ambient)<br>DIP–8 Package<br>SO–8 Package | $R_{\theta JA}$ | <br>100<br>145 | °C/W |
| Operating Ambient Temperature Range<br>DIP–8 Package<br>SO–8 Package | $T_A$ | <br>–40 to +125<br>–40 to +105 | °C |
| Operating Junction Temperature Range | $T_J$ | –40 to +150 | °C |
| Maximum Junction Temperature | $T_{J(max)}$ | 150 | °C |

**NOTE:** ESD data available upon request.

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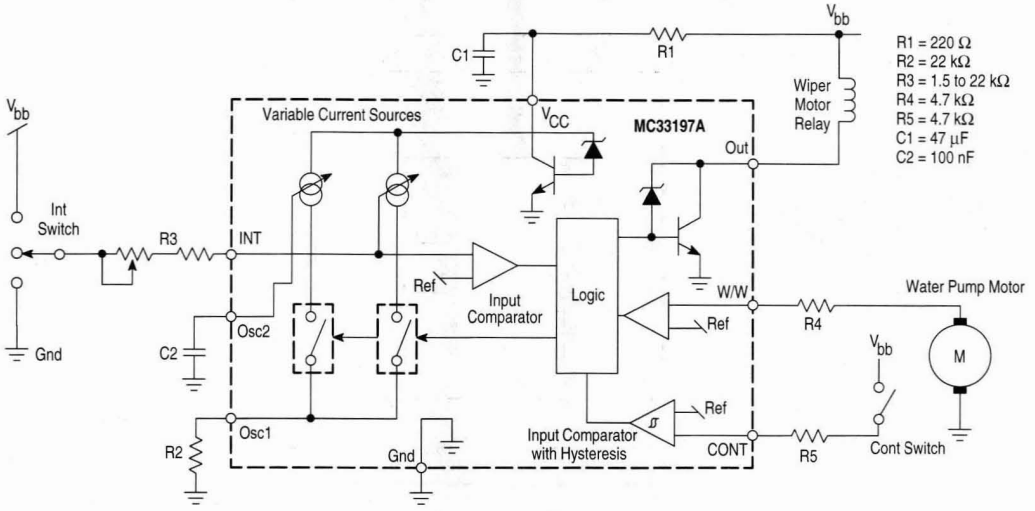
## Representative Block Diagram




This device contains 390 active transistors.

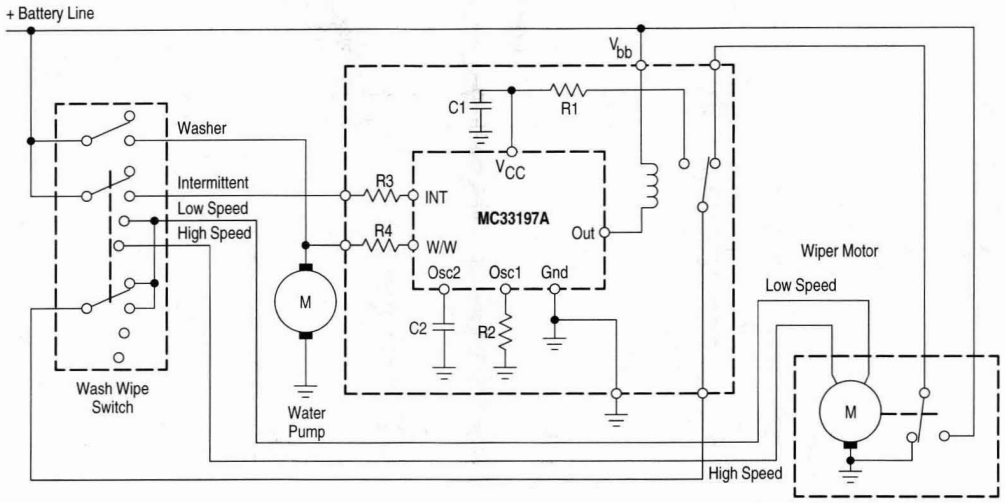
**ELECTRICAL CHARACTERISTICS** (–40°C ≤ $T_A$ ≤ +125°C, 8.0 V ≤ $V_{CC}$ ≤ 16 V, unless otherwise noted. Typical values reflect approximate mean at $T_A$ = 25°C with $V_{CC}$ = 14 V at the time of initial device characterization.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Functional Supply Voltage Range | $V_{CCF}$ | 8.0 | – | 18 | V |
| Operating Supply Voltage Range | $V_{CCOP}$ | 8.0 | – | 16 | V |
| Standby Supply Current ($V_{CC}$ = 16 V, R2 = 68 k) | $I_{CC}$ | – | 4.0 | 5.2 | mA |
| Supply Current INT Active (R3 = 2.5 k) | $I_{CC}$ | – | 7.0 | 8.4 | mA |
| Supply Current Relay "On" (R2 = 68 k) | $I_{CC}$ | – | 7.5 | 11.2 | mA |
| Supply Current INT and Relay "On" (R2 = 68 k, R3 = 2.5 k) | $I_{CC}$ | – | 10 | 14.5 | mA |
| Oscillator Variations with Supply Voltage and Temperature (excluding external component tolerances, C2 = 100 nF polyester capacitor) (Notes 1 & 2)<br>10 V ≤ $V_{bb}$ ≤ 16 V<br>8.0 V ≤ $V_{bb}$ ≤ 16 V | $K_{osc}$ | <br>–<br>– | <br>10<br>15 | <br>–<br>– | % |
| Relay Resistance | $R_L$ | 60 | – | – | Ω |
| Output Voltage ($I_{out}$ = 200 mA) | $V_{out}$ | – | 0.9 | 1.5 | V |
| Output Clamp Voltage ($I_{out}$ = 20 mA) | $V_{cl}$ | 19.5 | – | 22 | V |
| Oscillator Period Coefficient ($T_A$ = 25°C)<br>$V_{bb}$ = 13 V (Note 3)<br>$V_{bb}$ = 13 V (INT Connected to Gnd) (Note 4)<br>$V_{bb}$ = 13 V (INT Connected to $V_{bat}$, R1 = 220 Ω) (Note 4) | <br>$t_{b1}$<br>$t_{b2g}$<br>$t_{b2v}$ | <br>0.98<br>15.1<br>11.5 | <br>1.0<br>15.5<br>12.1 | <br>1.03<br>15.9<br>12.7 | – |
| CONT Threshold ($V_{CC}$ = 13 V) | $V_{ih}$ | 6.0 | – | 8.5 | V |
| CONT Threshold ($V_{CC}$ = 16 V) | $V_{ih}$ | – | $V_{CC}$/2 | – | V |

**NOTES:** 1. The oscillator frequency is defined by the current flowing through the external resistor R2. The voltage at the INT pin is ($V_{CC}$/2 – $V_{be}$) and hence the current flowing through R3 is different if R3 is connected to $V_{bb}$ or to Gnd because of the voltage drop across resistor R1. This voltage drop causes the oscillator coefficient for $t_{b2}$ to be different for the two cases of INT terminated to Gnd or to $V_{bb}$. Because of this, the oscillator coefficient is specified with a specific value of R1 whenever INT is connected to $V_{bb}$. If R1 is changed, the coefficient will change. Also, any extra current through the resistor R1 other than the current used by the device will cause timing deviations in $t_{b2}$ timings (as in the case where two devices are sharing a common R1 resistor).

2. The oscillator stability with temperature is dependent on the temperature coefficients of the external components. If the capacitance value of the external capacitor varies more than 5% over the parametric temperature range, the figures quoted for oscillator variation are not valid.
3. The $t_{b1}$ duration is given by coefficient 4 x R2 x C2 ($t_{b1}$ duration = $t_{b1}$ x 4 x R2 x C2).
4. The $t_{b2}$ duration is given by coefficient x R3 x C2 ($t_{b2}$ duration = $t_{b2}$ x R3 x C2).

**Figure 1. Intermittent Wash Wiper Typical Application**




This application shows the MC33197A with the external wirings and two speed wiper motor. This application has the Intermittent and Wash Wiper functions.

## INTRODUCTION

The MC33197A is a wiper timer control device designed for use in harsh automotive applications. The device can perform the intermittent, after wash, and continuous wiper timer functions.

The MC33197A is designed to directly drive a wiper motor relay. The MC33197A is suitable for both front and rear wiper applications. The MC33197A connects directly to the vehicle's battery voltage ($V_{bat}$) through a 220 Ω resistor used with a 47 µF de–coupling filter capacitor. The device has an internal oscillator controlled by one of two external resistors (R2 and R3) in addition to one external capacitor (C2), dependent on the application function required. The values of C2 and R2 determine the $t_{b1}$ time base. $T_{b1}$ is used to generate the relay wiper activation during the INT function (T3) and the after wash timing (T2) during the wash wipe mode. The values C2 and R3 determine the $t_{b2}$ time base. The $t_{b2}$ time base is used to generate the pause or intermittent time (T4).

The intermittent wiper function can generate intermittent timing (T4) from less than 500 ms to more than 30 seconds. The intermittent function of the device can be activated by the INT input connected to either ground or $V_{bat}$. The intermittent timing is externally adjustable by changing the value of resistor R3.

The wash wiper timer function detects the water pump motor's operation. When the pump motor activation is detected, the MC33197A turns the wiper on for the entire duration of the pump motor's activation. When the motor is turned off, it generates an after wash timing (T2) to maintain the wiping action. The W/W pin is connected to the water pump motor through a protection resistor (R4).

The MC33197A also has a continuous function, which activates the wiper relay whenever the CONT input is activated. The CONT input is connected to a switch through a protection resistor (R5). The CONT input comparator has an input threshold of $V_{bb}/2$ with hysteresis.

The device has internal debounce circuitry, based on the oscillator period. This provides filtering of the intermittent (INT) and wash wipe (W/W) input signals (see T1 Debounce Timing paragraph that follows). The device directly drives the wiper motor relay. It internally incorporates a 20 V free wheeling zener diode to protect the device against overvoltage spikes produced when relay is switched off.

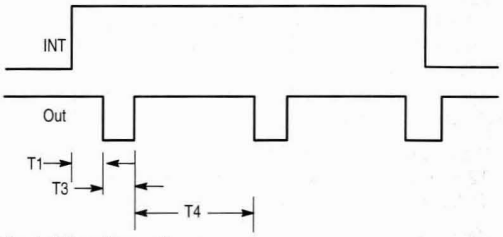
### Intermittent Operation

Conditions:

- W/W not connected or connected to ground.
- CONT not connected or connected to ground.
- INT connected to $V_{bb}$ or to ground.

In this configuration, the circuit will respond to the switching of INT to either $V_{bb}$ or ground after a time T1 (see T1 Debounce Timing). If INT is disconnected before the end of T1; no action will be taken. After a time T1, the output will be switched on for a duration, T3 = 16 x 4 x $t_{b1}$ and then switched off for a duration, T4 = 144 x 4 x $t_{b2}$. This sequence will continue to repeat so long as INT is disconnected from $V_{bb}$ or ground for a time duration greater than T1. If INT is disconnected during the time T3; the output will remain on for the remainder of T3. This is illustrated in the diagram on Figure 2.

**Figure 2. Switching Waveform INT Timing**



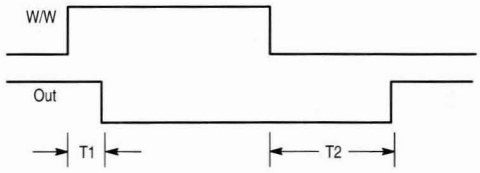

**Wash Wipe Operation**

Conditions:

- INT disconnected.
- CONT disconnected or connected to ground.

In this condition, the circuit will respond to the switching of W/W to $V_{bb}$ after a time T1 (see T1 Debounce Timing). If W/W is disconnected or connected to ground before the end of T1; no action will be taken. After a time T1; the circuit will perform as shown on Figure 3. The output will turn on and remain on for the duration of W/W. When W/W becomes inactive, the output will remain on for T2 = 96 x 4 x $t_{b1}$.

**Figure 3. Switching Waveform W/W Timing**



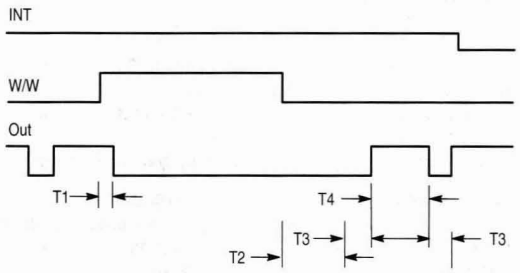

**Continuous Operation**

In this condition, the circuit responds to the switching of CONT to $V_{bb}$. If CONT is connected to $V_{bb}$, the output will turn on regardless of the state of any other input and remain on so long as CONT is active. This command operates directly on the relay output and does not interfere with any other timing. Therefore, the circuit will not be reset to a defined state.

**Wash Wiper and Intermittent Operation**

If W/W is activated during the time INT is also activated, the circuit will respond to W/W after a time T1 (see T1 Debounce Timing). The output will turn on after T1, and stay on for a time T2 + T3 after W/W is deactivated. Following this, normal operation of INT will occur. This is shown on Figure 4.

**Figure 4. Switching Waveform W/W and INT Active**




**T1 Debounce Timing**

The criteria for an input signal to be detected is that it should be active at two successive negative internal clock edges. The inputs are sampled on the negative edge of the internal clock. If two consecutive samples are the same, the input is detected as being in that state. Hence the time T1 from a signal becoming active to the time that the circuit responds can be anytime from 4 x $t_{b1}$ to 2 x 4 x $t_{b1}$ (due to synchronizing the input to the oscillator period) when the oscillator is oscillating with a time base of $t_{b1}$ and 4 x $t_{b2}$ to 2 x 4 x $t_{b2}$, when the oscillator is oscillating with a time base of $t_{b2}$.

The following table summarizes all T1 debounce timings:

| Condition | Debounce Time |
|---|---|
| INT Active | 4 x $t_{b1}$ to 2 x 4 x $t_{b1}$ |
| INT Inactive | 4 x $t_{b1}$ to 2 x 4 x $t_{b1}$ |
| W/W Active When INT Inactive | 4 x $t_{b1}$ to 2 x 4 x $t_{b1}$ |
| W/W Active When INT Active During T3 | 4 x $t_{b1}$ to 2 x 4 x $t_{b1}$ |
| W/W Active When INT Active During T4 | 4 x $t_{b2}$ to 2 x 4 x $t_{b2}$ |

**Two MC33197A Devices Using One Decoupling Resistor and Capacitor**

Two devices may be connected to the power source using a common R1 resistor for protection against overvoltages. If this is done it should be noted that the current flowing through R1 is increased and hence the voltage drop across R1 is increased.

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**Overvoltage Protection**

In reference to the Block Diagram and Typical Application, all of the foregoing operational cases require:

R1 ≥ 100 Ω, C1 ≥ 47 µF

R3 ≥ 1.0 kΩ, R4 ≥ 4.7 kΩ, R5 ≥ 4.7 kΩ

The circuit will not operate during the transient conditions. By using the above component values, the circuit will be able to sustain the following overvoltages on $V_{bb}$ without permanent damage:

1. +28 V for 5 minutes
2. –15 V for 5 minutes
3. –16 V cycled off for 1.0 minute
4. +80 V pulse decaying exponentially to 8.0 V in 400 ms repeated 3 times at 1.0 minute intervals.
5. ± 300 V pulse decaying exponentially to 30 V in 300 ms with a maximum energy of 1.0 Joule.
6. ±100 V pulse decaying exponentially to 10 V in 2 ms.

**Recommended External Component Values**

Below are the recommended component values to ensure the device will operate properly, and that all specified parameters will stay within their tolerances.

R1 should be greater than 100 Ω; recommended value of 220 Ω. R1 can be up to 500 Ω, but in this case the $t_{b2v}$ parameter could be out of it's specified value (see Electrical Characteristics and Note 1). Also, the minimum operating voltage range should be greater than 8.0 V. The following values should be adhered to:

10 kΩ ≤ R2 ≤ 68 kΩ

1.5 kΩ ≤ R3 ≤ 47 kΩ

R4 ≥ 4.7 kΩ

R5 ≥ 4.7 kΩ

C1 ≥ 47 uF

47 nF ≤ C2 ≤ 470 nF

**Application Information**

The following is an example of timing calculations using the following external components values:

R2 = 22 kΩ, R3 = 2.2 kΩ, C2 = 100 nF (Referring to Block Diagram and Typical Application).

Oscillator Time Base Calculation:

$t_{b1}$ duration = $t_{b1}$ x 4 x R2 x C2 = 1 x 4 x 27e3 x 100e–9 = 10.8 ms

$t_{b2}$ duration_g (INT to Gnd) = $t_{b2g}$ x R3 x C2 = 15.5 x 2.2e3 x 100e–9 = 3.41 ms

$t_{b2}$ duration_v (INT to $V_{bb}$) = $t_{b2v}$ x R3 x C2 = 12.1 x 2.2e3 x 100e–9 = 2.66 ms

Intermittent timing calculation:

T3 = 16 x 4 x $t_{b1}$ duration = 16 x 4 x 10.8 ms = 691 ms

T4 = 144 x 4 x $t_{b2}$ duration_g = 144 x 4 x 3.41 ms = 1.96 s (INT connected to Gnd)

T4 = 144 x 4 x $t_{b2}$ duration_v = 144 x 4 x 2.66 ms = 1.53 s (INT connected to $V_{bb}$)

Wash wipe timing calculation:

T2 = 96 x 4 x $t_{b1}$ = 96 x 4 x 10.8 ms = 4.15 s

T1 Debounce Time Calculation (see T1 Debounce Timing)

When oscillator is oscillating at $t_{b1}$:

T1 minimum = 4 x $t_{b1}$ = 4 x 10.8 ms = 43.2 ms

T1 maximum = 2 x 4 x $t_{b1}$ = 2 x 4 x 10.8 ms = 86.4 ms

When oscillator is oscillating at $t_{b2}$:

T1 minimum (INT connected to Gnd, $t_{b2g}$) = 4 x $t_{b2}$ = 4 x 3.41 ms = 13.6 ms

T1 maximum (INT connected to Gnd, $t_{b2g}$) = 2 x 4 x $t_{b2}$ = 2 x 4 x 3.41 ms = 27.3 ms

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MOTOROLA

# Automotive ISO 9141 Serial Link Driver

The MC33199D is a serial interface circuit used in diagnostic applications. It is the interface between the microcontroller and the special K and L Lines of the ISO diagnostic port. The MC33199D has been designed to meet the "Diagnosis System ISO 9141" specification.

The device has a bi–directional bus K Line driver, fully protected against short circuits and over temperature. It also includes the L Line receiver, used during the wake up sequence in the ISO transmission.

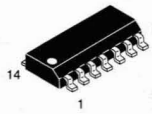
The MC33199 has a unique feature which allows transmission baud rate up to 200 k baud.

- Electrically Compatible with Specification "Diagnosis System ISO 9141"
- Transmission Speed Up to 200 k Baud
- Internal Voltage Reference Generator for Line Comparator Thresholds
- TXD, RXD and LO Pins are 5.0 V CMOS Compatible
- High Current Capability of DIA Pin (K Line)
- Short Circuit Protection for the K Line Input
- Over Temperature Shutdown with Hysteresis
- Large Operating Range of Driver Supply Voltage
- Full Operating Temperature Range
- ESD Protected Pins

**MC33199**

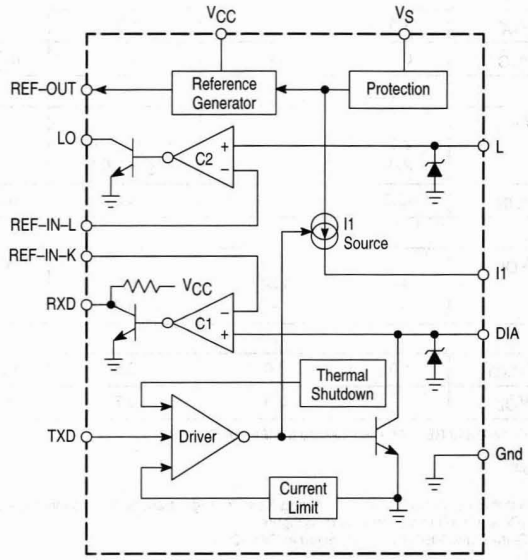
**ISO 9141**
**SERIAL LINK DRIVER**

**SEMICONDUCTOR**
**TECHNICAL DATA**



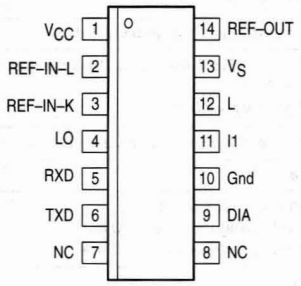

**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**Simplified Application**




This device contains 94 active transistors.

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33199D | $T_A$ = – 40° to +125°C | SO–14 |

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**MAXIMUM RATINGS** (Note 1)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| $V_S$ Supply Pin<br>DC Voltage Range<br>Transient Pulse (Note 2) | <br>$V_S$<br>$V_{pulse}$ | <br>–0.5 to +40<br>–2.0 to +40 | V |
| $V_{CC}$ Supply DC Voltage Range | $V_{CC}$ | –0.3 to +6.0 | V |
| DIA and L Pins (Note 2)<br>DC Voltage Range<br>Transient Pulse (Clamped by Internal Diode)<br>DC Source Current<br>DIA Low Level Sink Current | – | <br>–0.5 to +40<br>–2.0<br>–50<br>Int. Limit | <br>V<br>V<br>mA<br>mA |
| TXD DC Voltage Range | – | –0.3 to $V_{CC}$ + 0.3 | V |
| REF–IN DC Voltage Range<br>$V_S < V_{CC}$<br>$V_S > V_{CC}$ | – | <br>–0.3 to $V_{CC}$<br>–0.3 to $V_S$ | V |
| ESD Voltage Capability (Note 3) | $V_{(ESD)}$ | ±2000 | V |

**NOTES:** 1. The device is compatible with Specification: "Diagnosis System ISO 9141".
2. See the test circuit (Figure 23). Transient test pulse according to ISO 76371 and DIN 40839; highest test levels.
3. Human Body Model; C = 100 pF, R = 1500 Ω.

**THERMAL RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Storage Temperature | $T_{stg}$ | –55 to +150 | °C |
| Operating Junction Temperature | $T_J$ | –40 to +150 | °C |
| Thermal Resistance, Junction–to–Ambient | $R_{\theta JA}$ | 180 | °C/W |
| Maximum Power Dissipation (@ $T_A$ = 105°C) | $P_D$ | 250 | mW |

**ELECTRICAL CHARACTERISTICS** (– 40°C ≤ $T_A$ ≤ 125°C, 4.5 V ≤ $V_{CC}$ ≤ 5.5 V, 4.5 V ≤ $V_S$ ≤ 20 V, unless otherwise noted. Typical values reflect approximate mean at 25°C, nominal $V_{CC}$ and $V_S$, at time of device characterization.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **$V_{CC}$ PIN 1** | | | | | |
| $V_{CC}$ Supply Voltage Range | $V_{CC}$ | 4.5 | – | 5.5 | V |
| $V_{CC}$ Supply Current (Note 1) | $I_{CC}$ | 0.5 | 1.0 | 1.5 | mA |
| **REF–IN–L PIN 2 AND REF–IN–K PIN 3** | | | | | |
| REF–IN–L and REF–IN–K Input Voltage Range<br>For $0 < V_S < V_{CC}$<br>For $V_{CC} < V_S < 40$ V | $V_{inref}$ | <br>2.0<br>2.0 | <br>–<br>– | <br>$V_{CC}$ – 2.0 V<br>$V_S$ – 1.0 V | V |
| REF–IN–L and REF–IN–K Inputs Currents | $I_{VIN}$ | –5.0 | – | 5.0 | µA |
| **LO PIN 4** | | | | | |
| LO Open Collector Output<br>Low Level Voltage @ $I_{out}$ = 1.0 mA<br>Low Level Voltage @ $I_{out}$ = 4.0 mA | $V_{OL}$ | <br>–<br>– | <br>0.34<br>– | <br>0.7<br>0.8 | V |
| **RXD PIN 5** | | | | | |
| Pull–Up Resistor to $V_{CC}$ | $R_{RXD}$ | 1.5 | 2.0 | 2.5 | kΩ |
| Low Level Voltage @ $I_{out}$ = 1.0 mA | $V_{OL}$ | – | 0.3 | 0.7 | V |

**NOTES:** 1. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load. REF–IN–L and REF–IN–K connected to REF–OUT.
2. $0 < V_{CC} < 5.5$ V, $0 < V_S < 40$ V, $0 < V_{DIA} < 20$ V, TXD high or floating.
3. When an over temperature is detected, the DIA output is forced "off".
4. $0 < V_{CC} < 5.5$ V, $0 < V_S < 40$ V, $0 < V_L < 20$ V.
5. At static "High" or "Low" level TXD, the current source I1 delivers a current of 3.0 mA (typ). Only during "Low" to "High" transition, does this current increase to a higher value in order to charge the K Line capacitor (CL < 4.0 nF) in a short time (see Figure 3).
6. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load, REF–IN–L and REF–IN–K connected to REF–OUT.

**ELECTRICAL CHARACTERISTICS (continued)** ($-40°C \le T_A \le 125°C$, $4.5\ V \le V_{CC} \le 5.5\ V$, $4.5\ V \le V_S \le 20\ V$, unless otherwise noted. Typical values reflect approximate mean at 25°C, nominal $V_{CC}$ and $V_S$, at time of device characterization.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **TXD PIN 6** | | | | | |
| High Level Input Voltage | $V_{IH}$ | $0.7\ V_{CC}$ | 2.8 | – | V |
| Low Level Input Voltage | $V_{IL}$ | – | 2.0 | $0.3\ V_{CC}$ | V |
| Input Current @ $0 < V_S < 40\ V$<br>TXD at High Level<br>TXD at Low Level | <br>$I_H$<br>$I_L$ | <br>–200<br>–600 | <br>–<br>– | <br>30<br>–100 | µA |
| **DIA INPUT/OUTPUT PIN 9** | | | | | |
| Low Level Output Voltage @ I = 30 mA | $V_{OL}$ | 0 | 0.35 | 0.8 | V |
| Drive Current Limit | $I_{Lim}$ | 40 | – | 120 | mA |
| High Level Input Threshold Voltage (REF–IN–K Connected to REF–OUT) | $V_{IH}$ | $V_{ref}$ min + 0.25 V | $V_{ref}$ + 0.325 V | $V_{ref}$ max + 0.4 V | V |
| Low Level Input Threshold Voltage (REF–IN–K Connected to REF–OUT) | $V_{IL}$ | $V_{ref}$ min – 0.2 V | $V_{ref}$ – 0.125 V | $V_{ref}$ max – 0.05 V | V |
| Input Hysteresis | $V_{Hyst}$ | 300 | 450 | 600 | mV |
| Positive Clamp @ 5.0 mA | $V_{Cl+}$ | 37 | 40 | 44 | V |
| Negative Clamp @ – 5.0 mA | $V_{Cl-}$ | –1.5 | –0.6 | –0.3 | V |
| Leakage Current (Note 2) | $I_{Leak}$ | 4.0 | 10 | 16 | µA |
| Over Temperature Shutdown (Note 3) | $T_{Lim}$ | 155 | – | – | °C |
| **L INPUT PIN 12** | | | | | |
| High Level Input Threshold Voltage (REF–IN–L Connected to REF–OUT) | $V_{IH}$ | $V_{ref}$ min + 0.25 V | $V_{ref}$ + 0.325 V | $V_{ref}$ max + 0.4 V | V |
| Low Level Input Threshold Voltage (REF–IN–L Connected to REF–OUT) | $V_{IL}$ | $V_{ref}$ min – 0.2 V | $V_{ref}$ – 0.125 V | $V_{ref}$ max – 0.05 V | V |
| Input Hysteresis | $V_{Hyst}$ | 300 | 450 | 600 | mV |
| Leakage Current (Note 4) | $I_{Leak}$ | 4.0 | 10 | 16 | µA |
| Positive Clamp @ 5.0 mA | $V_{Cl+}$ | 37 | 40 | 44 | V |
| Negative Clamp @ – 5.0 mA | $V_{Cl-}$ | –1.5 | –0.6 | –0.3 | V |
| **I1 PIN 11** | | | | | |
| Static Source Current | $I1_s$ | –4.0 | –3.0 | –2.0 | mA |
| Static Saturation Voltage ($I1_s = -2.0$ mA) | $V_{I1(sat)}$ | $V_S - 1.2$ | $V_S - 0.8$ | $V_S$ | V |
| Dynamic Source Current (Note 5) | $I1_d$ | –120 | –80 | –40 | mA |
| Dynamic Saturation Voltage ($I_{I1(sat)} = -40$ mA) | $V_{I1(dsat)}$ | $V_S - 2.7$ | $V_S - 0.85$ | $V_S$ | V |
| **VS PIN 13** | | | | | |
| $V_S$ Supply Voltage Range | $V_S$ | 4.5 | – | 20 | V |
| $V_S$ Supply Current (Note 6) | $I_S$ | 0.5 | 1.3 | 2.0 | mA |

**NOTES:** 1. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load. REF–IN–L and REF–IN–K connected to REF–OUT.
2. $0 < V_{CC} < 5.5\ V$, $0 < V_S < 40\ V$, $0 < V_{DIA} < 20\ V$, TXD high or floating.
3. When an over temperature is detected, the DIA output is forced "off".
4. $0 < V_{CC} < 5.5\ V$, $0 < V_S < 40\ V$, $0 < V_L < 20\ V$.
5. At static "High" or "Low" level TXD, the current source I1 delivers a current of 3.0 mA (typ). Only during "Low" to "High" transition, does this current increase to a higher value in order to charge the K Line capacitor (CL < 4.0 nF) in a short time (see Figure 3).
6. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load, REF–IN–L and REF–IN–K connected to REF–OUT.

**ELECTRICAL CHARACTERISTICS (continued)** ($-40°C \le T_A \le 125°C$, $4.5\ V \le V_{CC} \le 5.5\ V$, $4.5\ V \le V_S \le 20\ V$, unless otherwise noted. Typical values reflect approximate mean at 25°C, nominal $V_{CC}$ and $V_S$, at time of device characterization.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **REF–OUT PIN 14** | | | | | |
| Output Voltage<br>$3.0 < V_S < 5.6$ V and $I_{RO} = \pm 10\ \mu A$<br>$5.6 < V_S < 18$ V and $I_{RO} = \pm 10\ \mu A$<br>$18 < V_S < 40$ V and $I_{RO} = \pm 10\ \mu A$ | $V_{ref}$ | <br>2.7<br>0.5 x $V_S$<br>8.5 | <br>–<br>–<br>– | <br>3.3<br>0.56 x $V_S$<br>10.8 | V |
| Maximum Output Current | $I_{out}$ | –50 | – | 50 | µA |
| Pull–Up Resistor to $V_{CC}$ | $R_{PU}$ | 3.0 | 8.0 | 12 | kΩ |

**NOTES:** 1. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load. REF–IN–L and REF–IN–K connected to REF–OUT.
2. $0 < V_{CC} < 5.5$ V, $0 < V_S < 40$ V, $0 < V_{DIA} < 20$ V, TXD high or floating.
3. When an over temperature is detected, the DIA output is forced "off".
4. $0 < V_{CC} < 5.5$ V, $0 < V_S < 40$ V, $0 < V_L < 20$ V.
5. At static "High" or "Low" level TXD, the current source I1 delivers a current of 3.0 mA (typ). Only during "Low" to "High" transition, does this current increase to a higher value in order to charge the K Line capacitor (CL < 4.0 nF) in a short time (see Figure 3).
6. Measured with TXD = $V_{CC}$, I1 = $V_S$, DIA and L high, no load, REF–IN–L and REF–IN–K connected to REF–OUT.

**DYNAMIC CHARACTERISTICS** ($-40°C \le T_A \le 125°C$, $4.5\ V \le V_{CC} \le 5.5\ V$, $4.5\ V \le V_S \le 20\ V$, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Transmission Speed | 1/t Bit | 0 | – | 200 k | Baud |
| High or Low Bit Time | t Bit | 5.0 | – | – | µs |
| RXD Output<br>Low to High Transition Delay Time<br>High to Low Transition Delay Time | <br>$t_{RDR}$<br>$t_{RDF}$ | <br>–<br>– | <br>–<br>– | <br>450<br>450 | ns |
| LO Output<br>Low to High Transition Delay Time<br>High to Low Transition Delay Time | <br>$t_{LDR}$<br>$t_{LDF}$ | <br>–<br>– | <br>–<br>– | <br>2.0<br>2.0 | µs |
| DIA Output<br>Low to High Transition Delay Time<br>High to Low Transition Delay Time | <br>$t_{DDR}$<br>$t_{DDF}$ | <br>–<br>– | <br>–<br>– | <br>650<br>650 | ns |
| I1 Output ($V_S - I1 > 2.7$ V)<br>Rise Time<br>Hold Time | <br>$t_{I1R}$<br>$t_{I1F}$ | <br>–<br>1.5 | <br>–<br>– | <br>0.3<br>4.5 | µs |

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**Figure 1. TXD to DIA AC Characteristic**

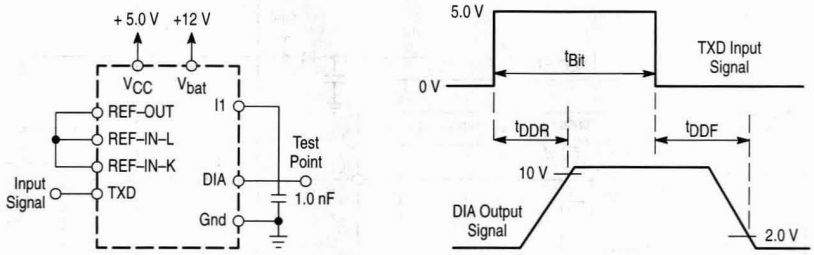



**Figure 2. DIA to TXD and L to LO AC Characteristics**

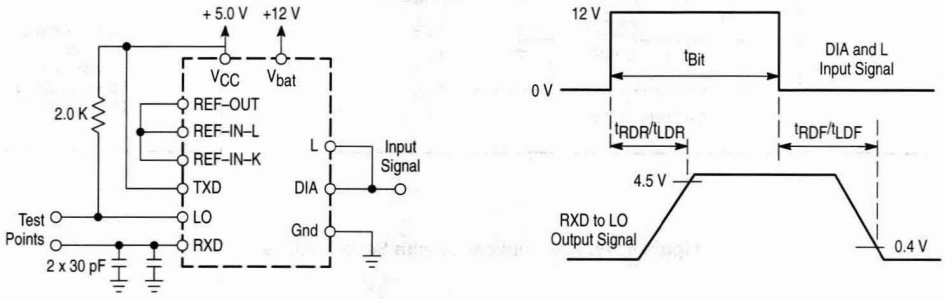
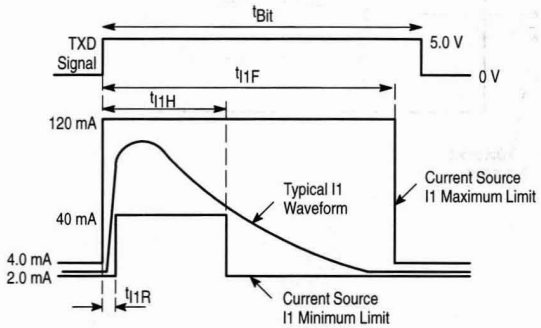



**Figure 3. Current Source I1 AC Characteristics**




At static "High" or "Low" level TXD, the current source I1 delivers a current of 3.0 mA (typ). Only during "Low" to "High" transition, does this current increase to a higher value in order to charge the K Line capacitor (Cl < 4.0 nF) in a short time.

**Figure 4. Current Source I1 and DIA Discharge Current Test Schematic**

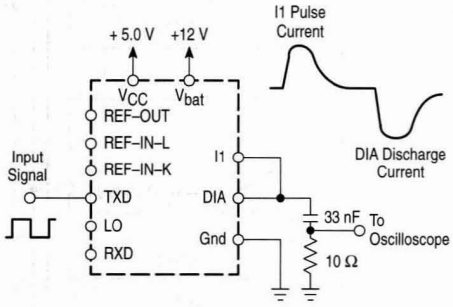



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**Figure 5. Logic Diagram and Application Schematic**

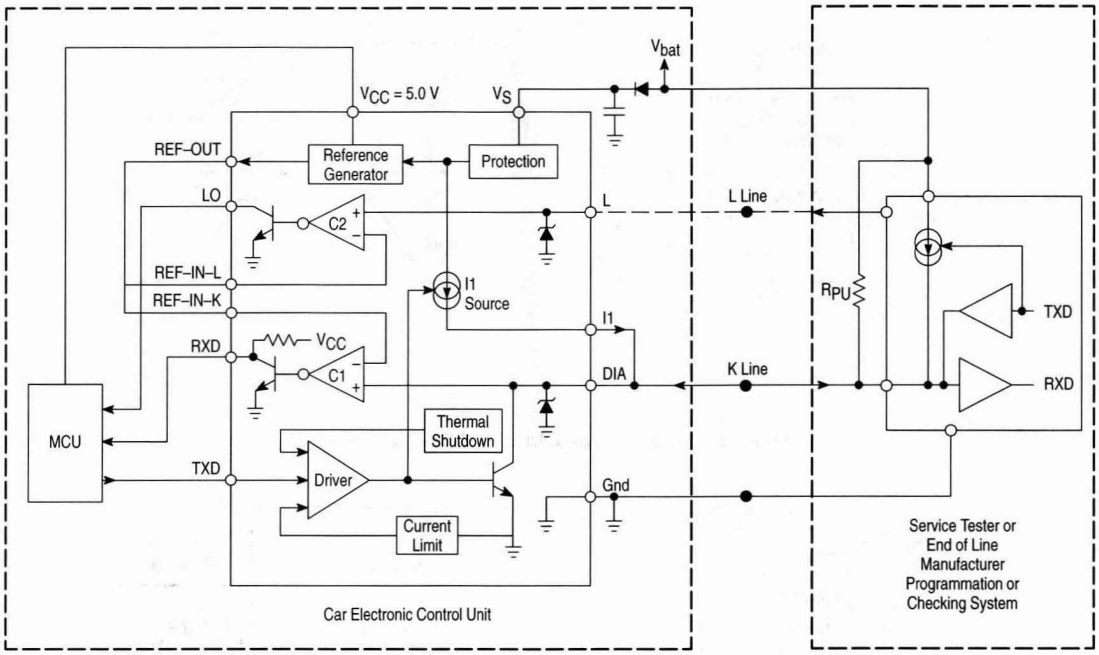


**Figure 6. Typical Application with Several ECUs**

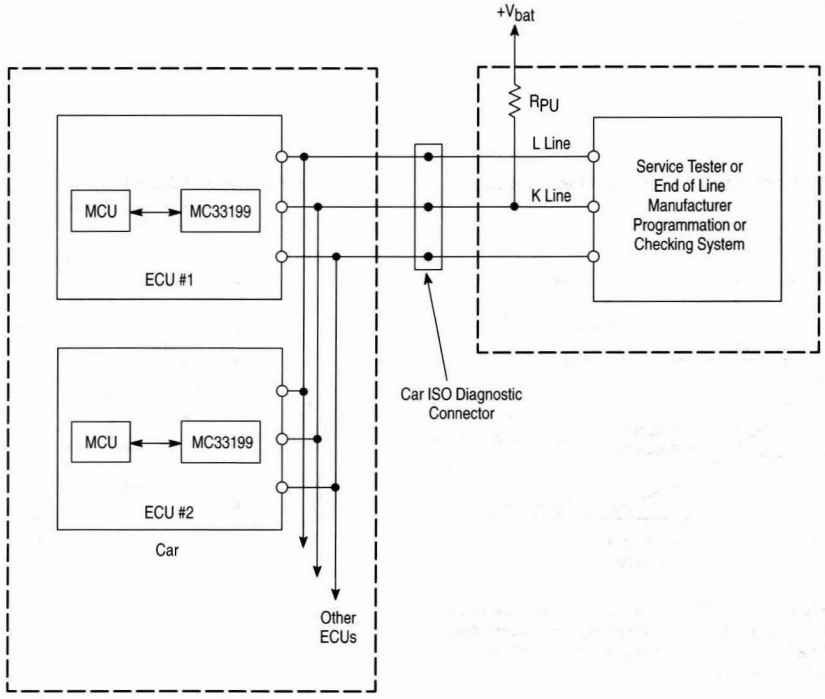


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**Figure 7. $I_{CC}$ Supply Current versus Temperature**

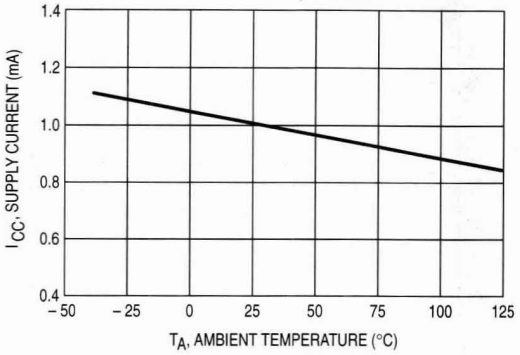


**Figure 8. $I_S$ Supply Current versus $V_S$ Supply Voltage**

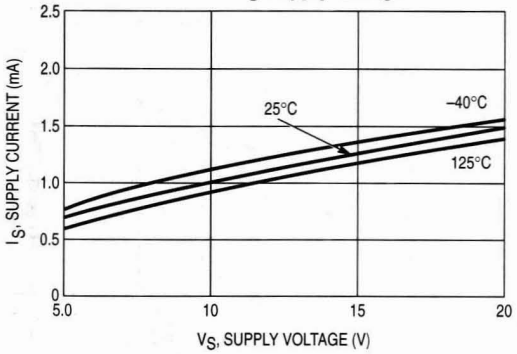


**Figure 9. $I_S$ Supply Current versus $V_S$ Supply Voltage**

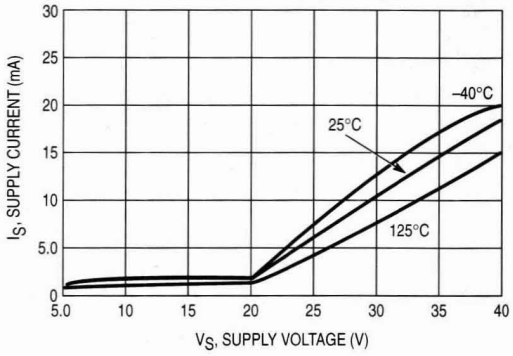


**Figure 10. $V_S$ Voltage versus $I_S$ Current**

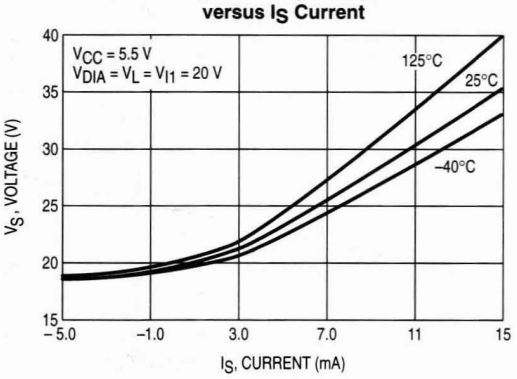


**Figure 11. REF–OUT Voltage versus $V_S$ Supply Voltage**

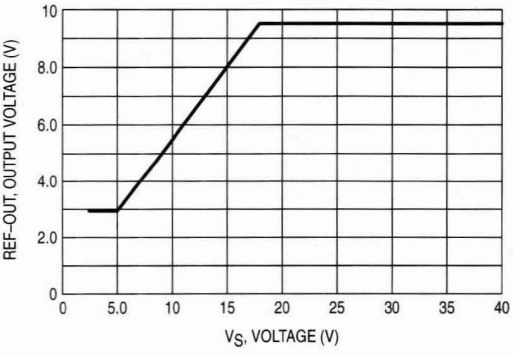


**Figure 12. REF–OUT Voltage versus REF–OUT Current**

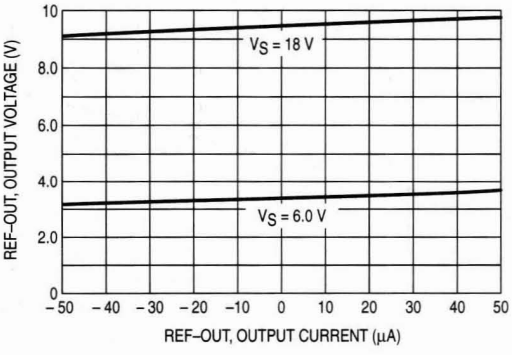


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**Figure 13. L and DIA Hysteresis versus Ambient Temperature**

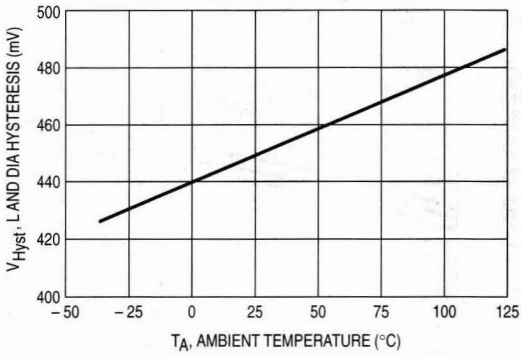


**Figure 14. L and DIA Current versus L and DIA Voltage**

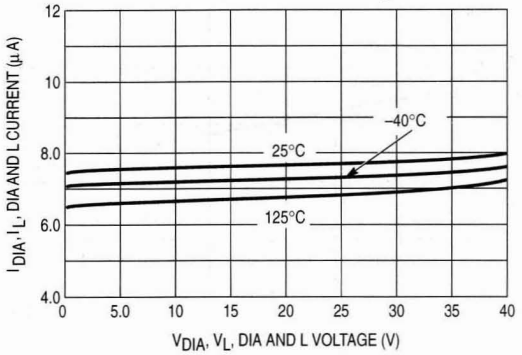


**Figure 15. DIA Saturation Voltage versus Temperature**

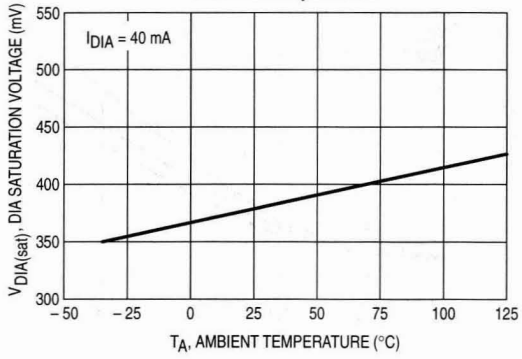


**Figure 16. DIA Current Limit versus Temperature**

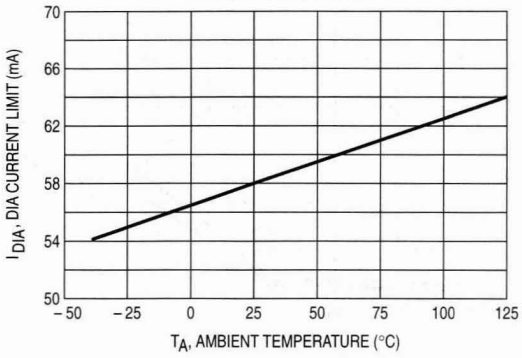


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**Figure 17. RXD Pull–Up Resistor versus Temperature**

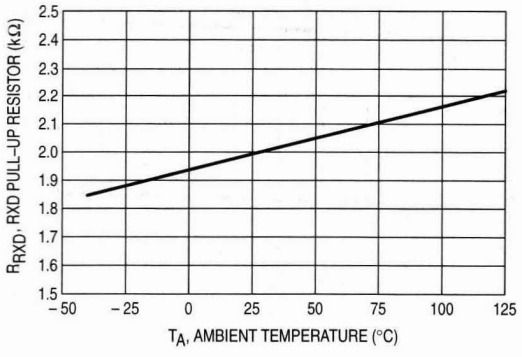


**Figure 18. TXD and LO Saturation Voltage versus Temperature**

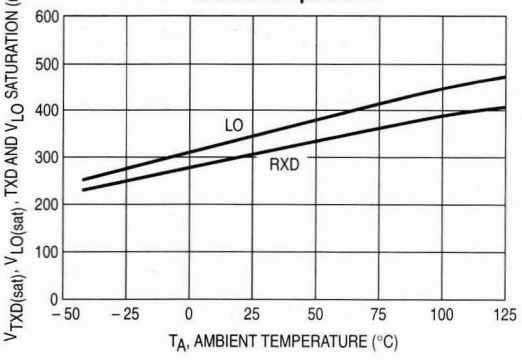

**Figure 19. I1 Saturation Voltage versus Temperature**

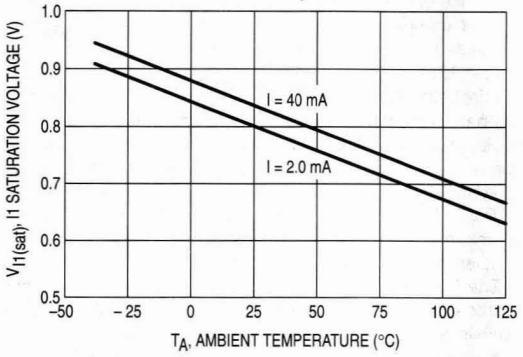


**Figure 20. I1 Output DC Current versus Temperature**

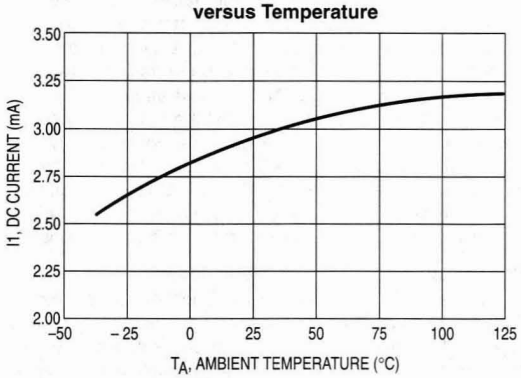


**Figure 21. I1 Output Pulse Current versus $V_S$ Supply Voltage**

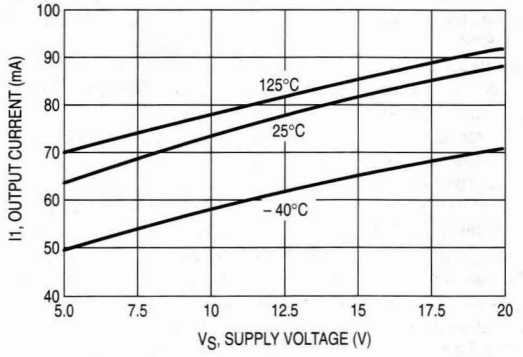


**Figure 22. I1 Pulse Current Width versus Temperature**

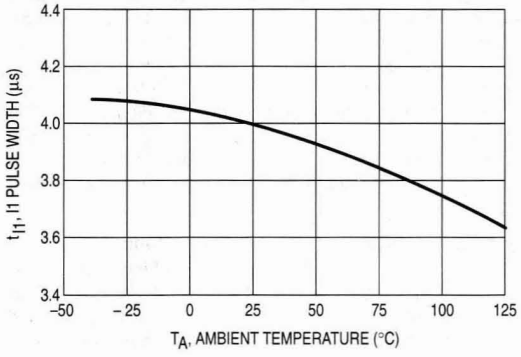


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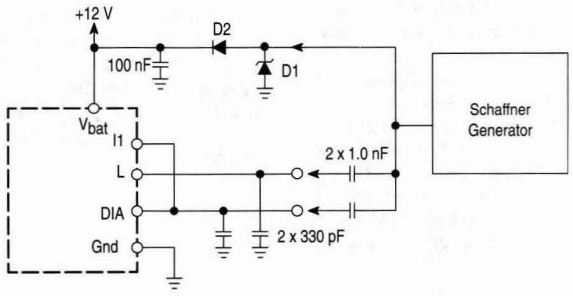
**Figure 23. Transient Test Circuit Using Schaffner Generator**




Test pulses are directly applied to $V_S$ and via a capacitor of 1.0 nF to DIA and L. The voltage $V_S$ is limited to – 2.0 V/40 V by the transient suppressor diode D1. Pulses can occur simultaneously or separately.

# MC33199

## INTRODUCTION

The MC33199 is a serial interface circuit used in diagnostic applications. It is the interface between the microcontroller and the special K and L Lines of the ISO diagnostic port. The MC33199 has been designed to meet the "Diagnosis System ISO 9141" specification.

This product description will detail the functionality of the device (see simplified application). The power supply and reference voltage generator will be discussed followed by the path functions between MCU, K and L Lines. A dedicated paragraph will discuss the special functionality of the I1 pin in it's ability to accommodiate high baud rate transmissions.

### Power Supplies and Reference Voltage

The device requires two power supplies to be used; a 5.0 V supply, $V_{CC}$, which is normally connected to the MCU supply. The device $V_{CC}$ pin is capable of sinking typically 1.0 mA during normal operation. A $V_{bat}$ supply voltage, $V_S$, is normally tied to the car's battery voltage. The $V_{bat}$ pin can sustain up to 40 V dc. Care should be taken to provide any additional reverse battery and transient voltage protection in excess of 40 V.

The voltage reference generator is supplied from both $V_{CC}$ and $V_{bat}$ pins. The voltage reference generator provides a reference voltage for the K and L Line comparator thresholds. The reference voltage is dependant on the $V_{bat}$ voltage; it is linear in relation to the $V_{bat}$ voltage for all $V_{bat}$ voltages between 5.6 V and 18 V. Below 5.6 V and over 18 V the reference voltage is clamped (see Figure 11). The REF–OUT pin connects the reference voltage out externally making it available for other application needs. The REF–OUT pin is capable of supplying a current of 50 µA (see Figure 12).

### Path Functions Between MCU, K and L Lines

The path function from the MCU to the K Line uses a driver to interface directly with the MCU through the TXD pin. The TXD pin is CMOS compatible. This driver controls the On–Off conduction of the power transistor. When the power transistor is On, it pulls the DIA pin low. This pin is known as K Line in the ISO 9141 specification. The DIA pin structure is open collector and requires an external pull–up resistor for use. Having an open collector without an internal pull–up resistor allows several MC33199 to be connected to the K Line while using a single pull–up resistor for the system (see Figure 6). In order to protect the DIA pin against short circuits to $V_{bat}$, the MC33199 incorporates an internal current limit (see Figure 16) and thermal shutdown circuit. The current limit feature makes it possible for the device to drive a K Line bus having a large parasitic capacitor value (see Special Functionality of I1 pin below).

The path from the DIA pin, or K Line, to the MCU is done through a comparator. The comparator threshold voltage is connected to REF–IN–K pin. It can be tied to the REF–OUT voltage if a $V_{bat}$ dependant threshold is required in the application. The second input of this comparator is connected internally to DIA pin. The output of this comparator is available at the RXD output pin and normally connects to an MCU I/O port. RXD pin has a 2.0 kΩ internal pull–up resistor.

The path from the L Line, used during a wake–up sequence of the transmission, to the MCU is done through a second comparator. The comparator threshold voltage is connected to REF–IN–L pin. The REF–IN–K pin can be tied to the REF–OUT voltage if a $V_{bat}$ dependant threshold is required in the application. The second input of this comparator is internally connected to L pin. The output of this comparator is available on LO output pin, which is also an open collector structure. The LO pin is normally connected to an MCU I/O port.

The DIA and L pins can sustain up to 40 V dc. Care should be taken to protect these pins from reverse battery and transient voltages exceeding 40 V.

The DIA and L pins both have internal pull–down current sources of typically 7.5 µA (see Figure 14). The L Line exhibits a 10 µA pull–down current. The DIA pin has the same behavior when it is in "off" state, that is when TXD is at logic high level.

### Special Functionality of I1 Pin

The MC33199 has a unique feature which accommodates transmission baud rates of up to 200 k baud. In practice, the K Line can be several meters long and have a large parasitic capacitance value. Large parasitic capacitance values will slow down the low to high transition of the K Line and limit the baud rate transmission. For the K Line to go from low to high level, the parasitic capacitor must first be charged, and can only be charged through the pull–up resistor. A low pull–up resistor value would result in fast charge time of the capacitor but also large output currents to be supplied causing a high power dissipation in the driver.

To avoid this problem, the MC33199 incorporates a dynamic current source which is temporarily activated at the low to high transition of the TXD pin when the DIA pin or K Line switches from a low to high level (see Figures 3 and 4).

This current source is available at the I1 pin. The I1 pin has a typical current capability of 80 mA. It is activated for 4.0 µs (see Figures 21 and 22) and is automatically disabled after this time. During this time it will charge the K Line parasitic capacitor. This extra current will quickly increase the K Line voltage up to $V_{bat}$, resulting in a reduced rise time of the K Line. With this feature, the MC33199 ensures baud rate transmission of up to 200 k baud.

During high to low transitions of the K Line, the parasitic capacitor of the line will be discharged by the output transistor of the DIA pin. In this case, the total current may exceed the internal current limitation of the DIA pin. If so, the current limit circuit will activate, limiting the discharge current to typically 60 mA (see Figures 4 and 16).

If a high baud rate is necessary, the I1 pin should be connected to the DIA as shown in the typical application circuit shown in Figure 5. The I1 pin can be left open, if the I1 functionality and high baud rate are not required for the application.

## PIN DESCRIPTION

**Pin 1: $V_{CC}$**

Power Supply pin; typically 5.0 V and requiring less than 1.5 mA.

**Pin 2: REF–IN–L**

Input reference for C2 comparator. This input can be connected directly to REF–OUT with or without a resistor network or to an external reference.

**Pin 3: REF–IN–K**

Input reference for C1 comparator. This input can be connected directly to REF–OUT with or without a resistor network or to an external reference.

**Pin 4: LO**

Output of C2 comparator and normally connected to a microcontroller I/O. If L input > (REF–IN–L + Hyst/2); output LO is in high state. If L< (REF–IN–L – Hyst/2); output LO is in low state and the output transistor is "on". This pin is an open collector structure and requires a pull–up resistor to be connected to $V_{CC}$. Output drive capability of this output is 5.0 mA.

**Pin 5: RXD**

Receive output normally connected to a microcontroller I/O. If DIA input > (REF–IN–L + Hyst/2); output LO is in high state. If DIA < (REF–IN–L – Hyst/2); output LO is in low state and the output transistor is "on". This pin has an internal pull–up resistor (typically 2.0 kΩ) connected to $V_{CC}$. Drive capability of this output is 5.0 mA.

**Pin 6: TXD**

Transmission input normally connected to a microcontroller I/O. This pin controls the DIA output. If TXD is high, the output DIA transistor is in the "off" state. If TXD is low, the DIA output transistor is "on".

**Pin 9: DIA**

Input/Output Diagnosis Bus line pin. This pin is an open collector structure and is protected against overcurrent and circuit shorts to $V_{bat}$ and $V_S$. Whenever the open collector transistor turns "on" (TXD low), the Bus line is pulled to ground and the DIA pin current is internally limited to nominal value of 60 mA. The internal power transistor incorporates a thermal shutdown circuit which forces the DIA output "off" in the event of an over temperature condition. The DIA pin is also the C1 comparator input. It is protected against both positive and negative overvoltages by an internal 40 V zener diode. This pin exhibits a constant input current of 7.5 μA.

**Pin 10: Gnd**

Ground reference for the entire device.

**Pin 11: I1**

Bus source current pin. It is normally tied to DIA pin and to the Bus line. The current source I1 delivers a nominal current of 3.0 mA at static "High" or "Low" levels of TXD. Only during "Low" to "High" transitions, does this current increase to a higher value so as to charge the key line capacitor (Cl < 4.0 nF) in a short time (see Figures 3 and 4).

**Pin 12: L**

Input for C2 comparator. This pin is protected against both positive and negative overvoltage by a 40 V zener diode. This L Line is a second independent input. It can be used for wake up sequence in ISO diagnosis or as an additional input bus line. This pin exhibits a constant input current of 7.5 μA.

**Pin 13: $V_S$**

12 V typical, or $V_{bat}$ supply pin for the device. This pin is protected against overvoltage transients.

**Pin 14: REF–OUT**

Internal reference voltage generator output pin. Its value depends on $V_S$ ($V_{bat}$) values. This output can be directly connected to REF–IN–L and REF–IN–K, or through a resistor network. Maximum current capability is 50 μA.

MOTOROLA

# MC33293A

*Advance Information*

## Quad Low Side Switch

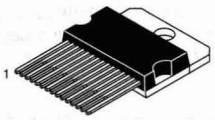
**QUAD LOW SIDE SWITCH**
**($R_{DS(on)}$ = 0.25 Ω Max per Output)**

**SEMICONDUCTOR TECHNICAL DATA**

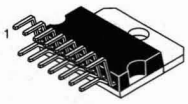
The MC33293A is a single monolithic integrated circuit designed for quad low side switching applications. This device was initially conceived as a quad injector driver for use in the harsh automotive environment but is well suited for many other applications. The MC33293A incorporates *SMARTMOS*™ technology having CMOS logic, bipolar and CMOS analog circuitry and DMOS power MOSFETs. All of the device inputs are CMOS compatible. The four output devices are N-channel power MOSFETs. A $\overline{\text{Fault}}$ detect output is provided to flag the existence of open loads (outputs ON or OFF) or shorted loads. If a short circuit is detected, the fault detect circuitry turns off the shorted output, but allows the others to function normally. An overvoltage ($V_{PWR}$) condition will turn off all outputs for the overvoltage duration. Each output functions independently and has a drain-to-gate diode clamp for inductive flyback voltage protection. A $\overline{\text{Single}}$/Dual select pin is incorporated to allow either individual output control or control of a pair of outputs from one input.

The MC33293A is parametrically specified over $-40°C \le T_A \le 125°C$ ambient temperature and a $9.0\ V \le V_{PWR} \le 14.5\ V$ supply.

- Designed to Operate with Supply Voltages of 5.5 V to 30 V
- CMOS Compatible Inputs with Active Pull-Downs
- Maximum 5.0 mA Quiescent Current
- $R_{DS(on)}$ of 0.25 Ω Maximum at 25°C, with $V_{PWR} \ge 9.0$ V
- Each Output Clamped to 65 V for Driving Inductive Loads
- Each Output Current Limited at 3.0 A to handle Incandescent Lamp Loads
- Active Low Output Fault Status with Interrogation Capability
- Open Load Detection (Output ON or OFF)
- Capable of Withstanding Reverse Battery
- Overvoltage Shutdown
- Short Circuit Detection and Shutdown with Automatic Retry




**T SUFFIX**
PLASTIC PACKAGE
CASE 821D




**TV SUFFIX**
PLASTIC PACKAGE
CASE 821C

**PIN CONNECTIONS**

Pin 1. Output 2
2. Output 1
3. Input 1
4. Input 2
5. Input 1 & 2
6. $\overline{\text{Single}}$/Dual
7. $V_{PWR}$
8. Gnd
9. N/C
10. $\overline{\text{Fault}}$
11. Input 3 & 4
12. Input 4
13. Input 3
14. Output 3
15. Output 4

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC33293AT | $T_J$ = –40° to +150°C | 15 Pin SIP |
| MC33293ATV | | |

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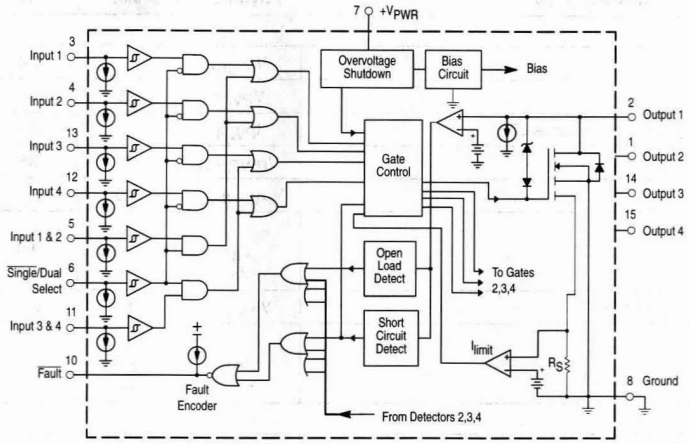
## Simplified Block Diagram




### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| $V_{CC}$<br>Steady-State<br>Transient Conditions | <br>$V_{PWR}$<br>$V_{PWR(pk)}$ | <br>–13 to 30<br>–13 to 60 | V |
| Input Pin Voltage | $V_{in}$ | – 0.5 to 7.5 | V |
| ESD Capability<br>Human Body Model (R = 1.5 kΩ, C = 200 pf) | $V_{ESD}$ | <br>2000 | V |
| Lead Current (per Output) | $I_{Out}$ | Internally Limited | A |
| Single Pulse Clamp Energy @ 25°C, 1.5 A | $E_{clamp}$ | 100 | mJ |
| Storage Temperature | $T_{stg}$ | – 55 to +150 | °C |
| Operating Temperature | $T_J$ | – 40 to +150 | °C |
| Lead Temperature (Wave Solder, 10 s) | $T_{solder}$ | 260 | °C |
| Power Dissipation @ $T_A$ = 105°C<br>Power Dissipation @ $T_A$ = 125°C<br>Derate for every °C above 25°C | $P_D$ | 11.25<br>6.25<br>0.25 | W<br><br>W/°C |
| Thermal Resistance Junction-to-Ambient | $R_{\theta JA}$ | 35 | °C/W |
| Thermal Resistance Junction-to-Case.<br>Any one O/P | $R_{\theta JC}$ | 4.0 | °C/W |

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**STATIC ELECTRICAL CHARACTERISTICS** (9.0 V ≤ $V_{PWR}$ ≤ 14.5 V and – 40°C ≤ $T_C$ ≤ +125°C, unless otherwise noted. Typical values are at 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **INPUT** | | | | | |
| Turn ON Threshold | $V_{on(th)}$ | — | 3.4 | 5.5 | V |
| Operating Voltage Range | $V_{PWR}$ | 5.5 | — | 30 | V |
| Quiescent Power Supply Current (All Inputs off) | $I_{PWR}$ | — | 2.2 | 5.0 | mA |
| Overvoltage Shutdown Range | $V_{PWR(ov)}$ | 30 | 35 | 38 | V |
| Overvoltage Reset Hysteresis | $V_{PWR(hys)}$ | 2.0 | 5.0 | 7.0 | V |
| Input Voltage<br>High ($I_{DS}$ = 1.0 A)<br>Low ($I_{DS}$ = 80 μA) | <br>$V_{IH}$<br>$V_{IL}$ | <br>3.0<br>— | <br>2.3<br>1.6 | <br>—<br>0.8 | V |
| Input High Hysteresis ($I_{DS}$ = 1.0 A) | $V_{IH(hys)}$ | 0.4 | 0.7 | — | V |
| Input Current<br>High ($V_{IH}$ = 3.0 V)<br>Low ($V_{IL}$ = 0.8 V) | <br>$I_{IH}$<br>$I_{IL}$ | <br>—<br>— | <br>11<br>11 | <br>50<br>50 | μA |
| **OUTPUT** | | | | | |
| Static Drain-Source On-Resistance<br>($I_{DS}$ = 1.0 A, $V_{PWR}$ = 13 V, $T_C$ = – 40°C to + 25°C)<br>($I_{DS}$ = 1.0 A, $V_{PWR}$ = 13 V, $T_C$ = +125°C)<br>($I_{DS}$ = 0.7 A, $V_{PWR}$ = 8.0 V, $T_C$ = + 25°C)<br>($I_{DS}$ = 0.4 A, $V_{PWR}$ = 5.5 V, $T_C$ = + 25°C) | $RDS_{(on)}$ | <br>—<br>—<br>—<br>— | <br>0.18<br>0.28<br>0.20<br>0.22 | <br>0.25<br>0.50<br>0.40<br>0.50 | Ω |
| Drain-Source Clamp Voltage<br>($I_{DS}$ = 20 mA, $V_{in}$ = 0 V, $t_{clamp}$ = 100 μs) | $BV_{DSS}$ | 55 | 64 | 80 | V |
| Zero Input Voltage Drain Current<br>($V_{DS}$ = 25 V, $V_{PWR}$ = 14.5 V)<br>($V_{DS}$ = 58 V, $V_{PWR}$ = 14.5 V) | $I_{DS(off)}$ | <br>10<br>— | <br>23<br>0.06 | <br>80<br>2.0 | <br>μA<br>mA |
| Source Drain Diode Forward Voltage ($I_{SD}$ = 1.0 A) | $V_{SD}$ | — | 0.62 | 1.4 | V |

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**STATIC ELECTRICAL CHARACTERISTICS (continued)** ($9.0\ V \le V_{PWR} \le 14.5\ V$ and $-40°C \le T_C \le +125°C$, unless otherwise noted. Typical values are at 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **FAULT STATUS OUTPUTT** | | | | | |
| Fault Status Pin | | | | | V |
| Low Voltage ($V_{PWR}$ = 14.5 V, $I_{stl}$ = 1.0 mA, open-load on Output 1, 2, 3 or 4. All inputs = 0 V) | $V_{stl}$ | — | 0.1 | 0.4 | |
| High Voltage, ($V_{PWR}$ = 14.5 V, $I_{sth}$ = – 30 μA, Note 1) | $V_{sth}$ | 3.0 | 4.7 | 5.5 | |
| **FAULT DETECTION** | | | | | |
| Output Limiting Current ($V_{PWR}$ = 13 V) | $I_{DS(limit)}$ | 3.0 | 4.0 | 6.0 | A |
| Over-Current Detect Voltage Threshold and | $V_{OC(limit)}$ | 2.4 | 3.7 | 5.0 | V |
| Output-Off Open-Load Detect Threshold Voltage | $V_{Ooff(th)}$ | 2.4 | 3.7 | 5.0 | |
| output-on open-load Detect Current | $I_{Oon(th)}$ | | | | mA |
| ($V_{PWR}$ = 13 V, $V_{in}$ = 5.0 V, $T_C$ = – 40°C) | | 20 | 80 | 190 | |
| ($V_{PWR}$ = 13 V, $V_{in}$ = 5.0 V, $T_C$ = + 25°C) | | 20 | 75 | 130 | |
| ($V_{PWR}$ = 13 V, $V_{in}$ = 5.0 V, $T_C$ = +125°C) | | 20 | 65 | 100 | |

**DYNAMIC ELECTRIC CHARACTERISTICS**

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OUTPUT TIMING** | | | | | |
| Output Driver Rise Time ($V_{CC}$ = 13 V, $R_L$ = 13 Ω, $t_r$ = Output Voltage change from 90% to 10%, see Figure 2) | $t_r$ | — | 2.3 | 10 | μs |
| Output Driver Fall Time ($V_{CC}$ = 13 V, $R_L$ = 13 Ω, $t_f$ = Output Voltage change from 10% to 90%, see Figure 2) | $t_f$ | — | 1.5 | 10 | μs |
| Output Delay Time ($V_{CC}$ = 13 V, $R_L$ = 13 Ω, | | | | | μs |
| $t_{on(dly)}$ = $V_{in}$ at 3.0 V to $V_O$ at 90%, see Figure 2) | $t_{on(dly)}$ | — | 3.2 | 10 | |
| $t_{off(dly)}$ = $V_{in}$ at 1.0 V to $V_O$ at 10%, see Figure 2) | $t_{off(dly)}$ | — | 5.9 | 15 | |
| **FAULT TIMING** | | | | | |
| Over-Current Sense Time (See Figure 5 or 6) ($V_{in}$ = 5.0 V, $R_L$ = 0.05 Ω, $V_{PWR}$ = 14.5 V, over-current duty cycle ≤ 10% $t_{oc}$ = time that $V_{Status}$ is > 1.0 V) | $t_{oc}$ | 10 | 55 | 250 | μs |
| Over-Current Refresh Time (See Figures 5 or 6) ($V_{in}$ = 5.0 V, $R_L$ = 0.05 Ω, $V_{PWR}$ = 14.5 V, over-current duty cycle ≤ 10% $t_{ref}$ = time that $V_{Status}$ is < 1.0 V) | $t_{ref}$ | 1.5 | 3.6 | 7.0 | ms |
| Output Open-Load Fault Status Delay Time | | | | | ms |
| ($V_{PWR}$ = 13 V, $V_{in}$ = 5.0 V, open-load on Output, $t_{os(on)}$ = time from $V_{in}$ = 3.0 V to $V_{Status}$ = 1.0 V, see Figure 3) | $t_{os(on)}$ | 1.0 | 2.2 | 4.0 | |
| ($V_{PWR}$ = 13 V, $V_{in}$ = 0 V, open-load on Output, | $t_{os(off)}$ | | | | μs |
| $t_{os(off)}$ = time from $V_{in}$ = 2.5 V to $V_{Status}$ = 1.0 V, see Figure 4) | | 1.0 | 19 | 40 | |
| Fault Status Reset Delay Time ($V_{PWR}$ = 13 V, $V_{in}$ = 0 V, see Figure 4) | $t_{s(reset)}$ | — | 2.0 | 10 | μs |

**NOTE:** 1. Negative current signifies current flowing out of device.

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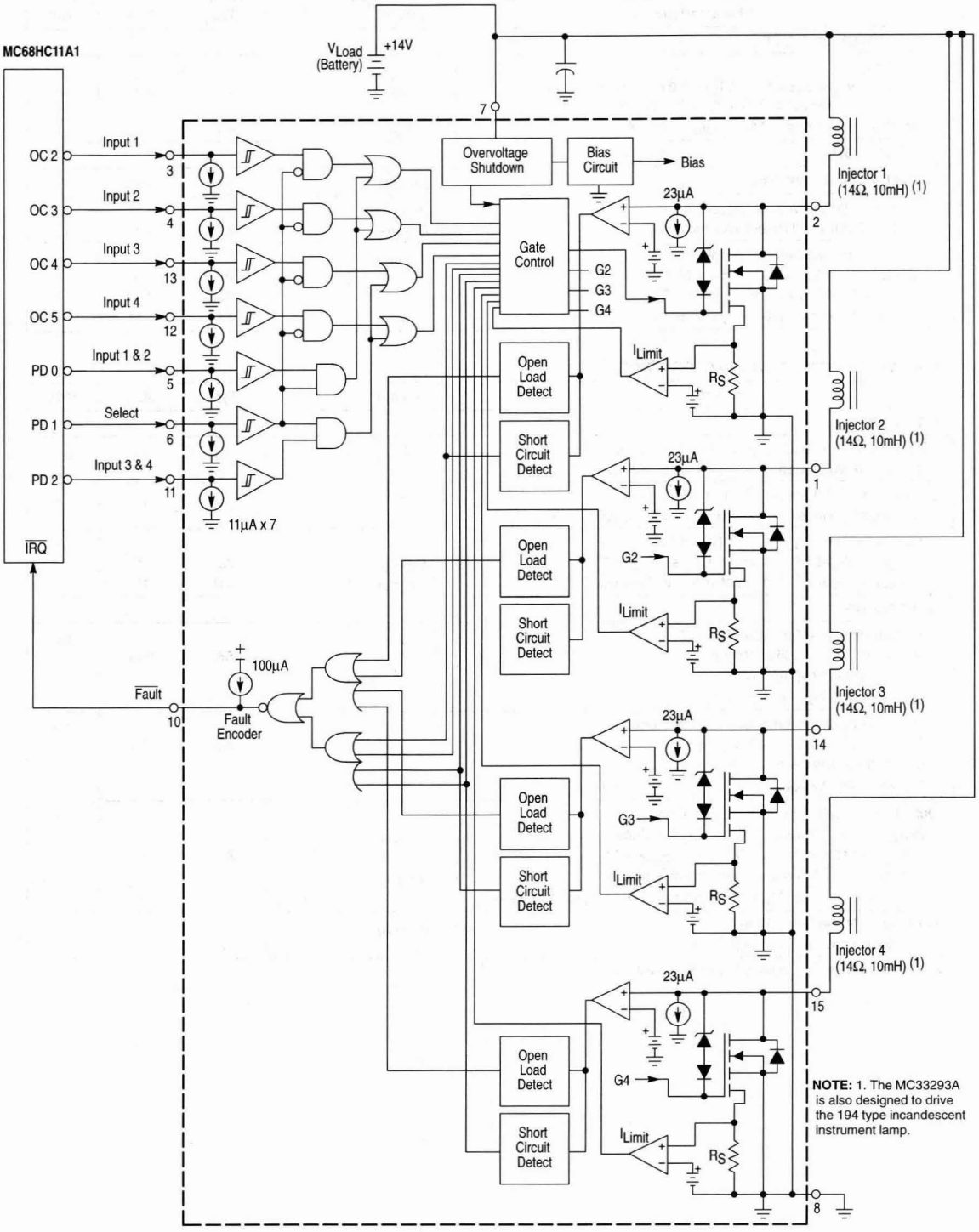
**Figure 1. Fuel Injector Application Block Diagram**




**NOTE:** 1. The MC33293A is also designed to drive the 194 type incandescent instrument lamp.

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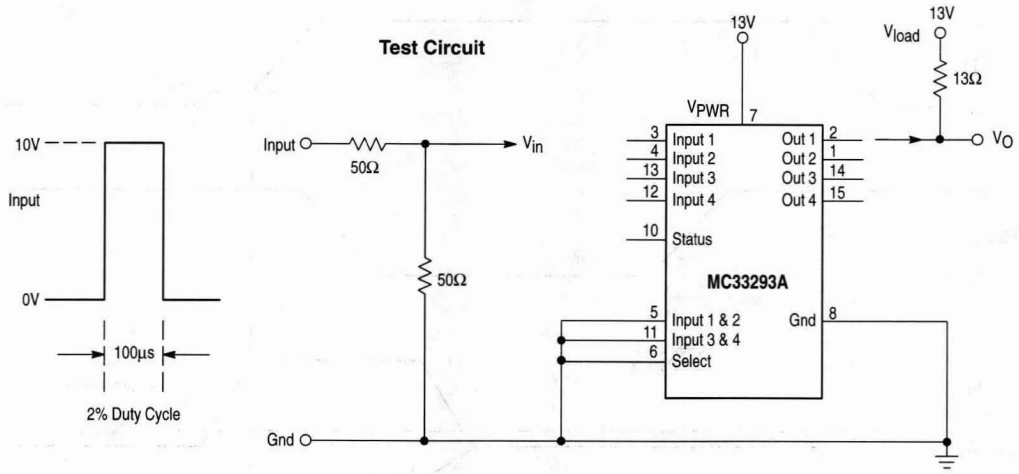
**Figure 2. Switching Speed Test Circuit and Response Times**



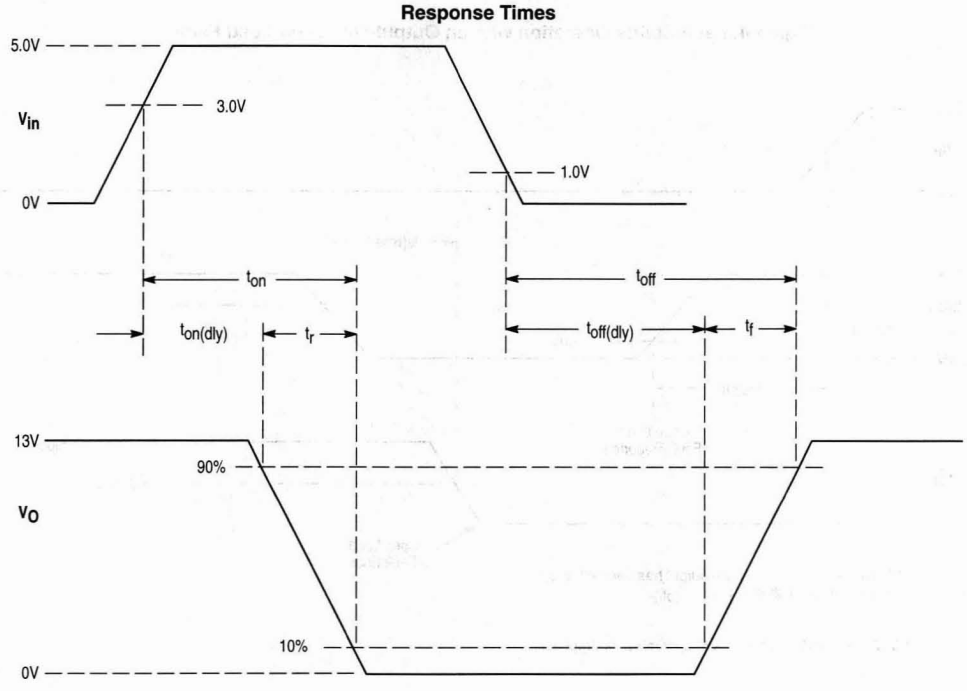




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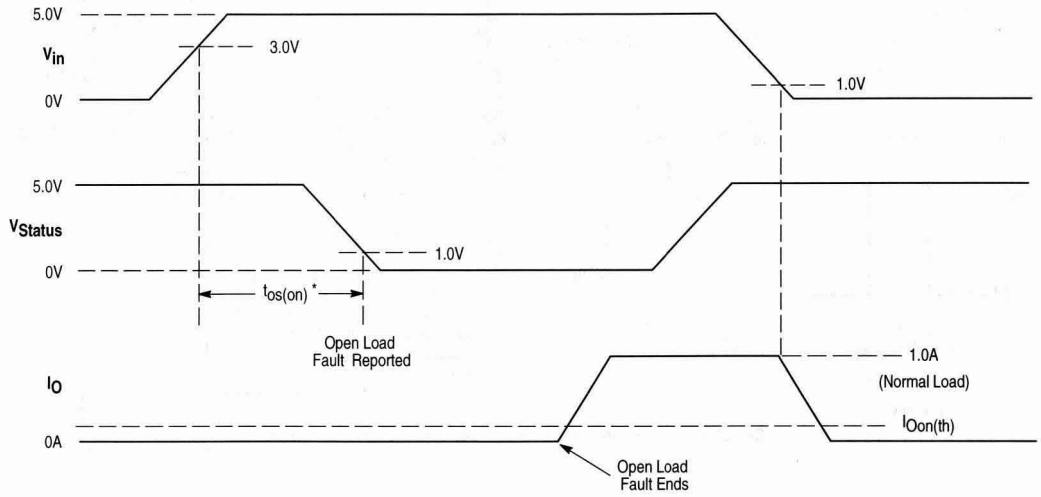
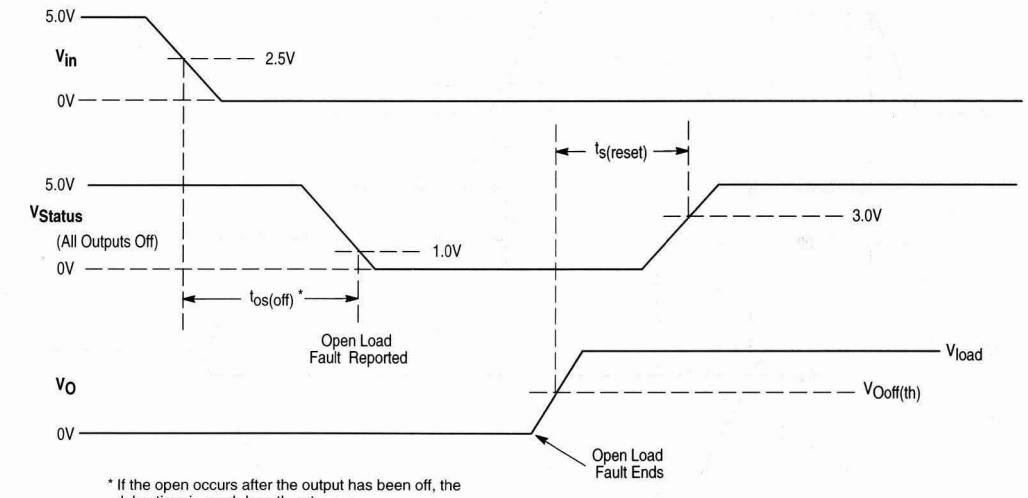
**Figure 3. Fault Status Operation with an Output-On, Open-Load Fault**




* If the open occurs after the output has been on, the delay time is much less than $t_{os(on)}$.

**NOTE**: Rise and fall times are exaggerated for emphasis.

**Figure 4. Fault Status Operation with an Output-Off, Open-Load Fault**




* If the open occurs after the output has been off, the delay time is much less than $t_{os(off)}$.

**NOTE**: Rise and fall times are exaggerated for emphasis.

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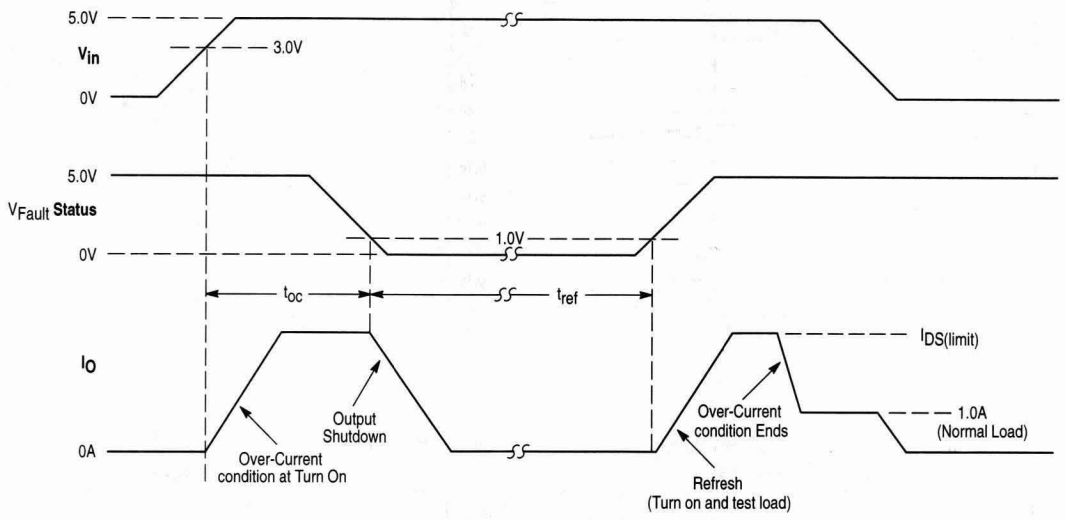
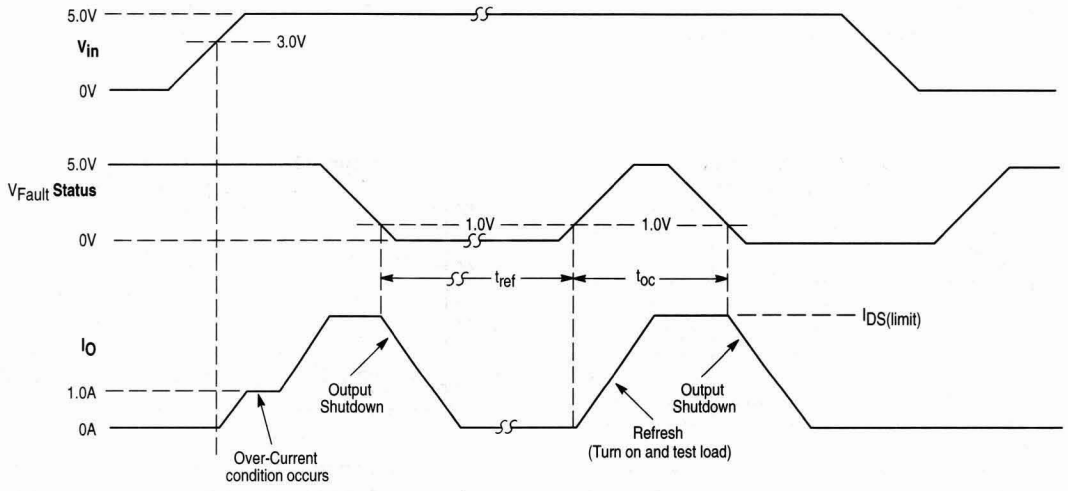
**Figure 5. Fault Status Operation with Turn On into an Over-Current Load**




**NOTE**: Rise and fall times are exaggerated for emphasis.

**Figure 6. Fault Status Operation with Over-Current Load after Turn On**




**NOTE**: Rise and fall times are exaggerated for emphasis.

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**Figure 7. Turn On Threshold Voltage versus Temperature**

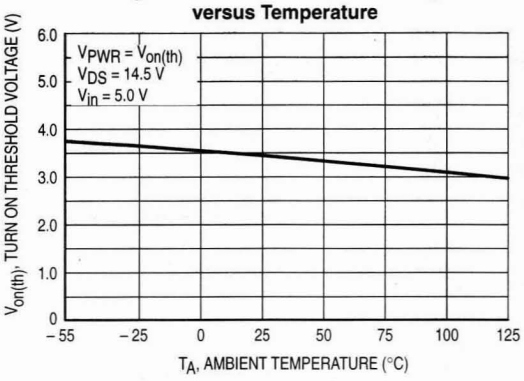


**Figure 8. Output On Resistance versus Temperature**

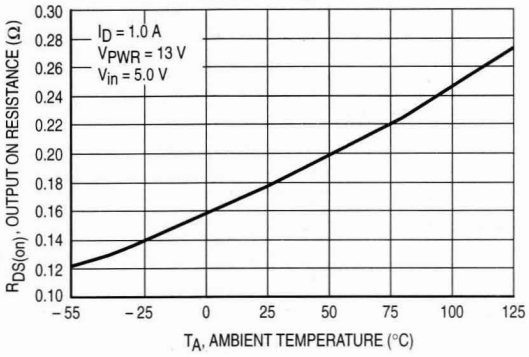


**Figure 9. Drain Source Clamp Voltage versus Temperature**

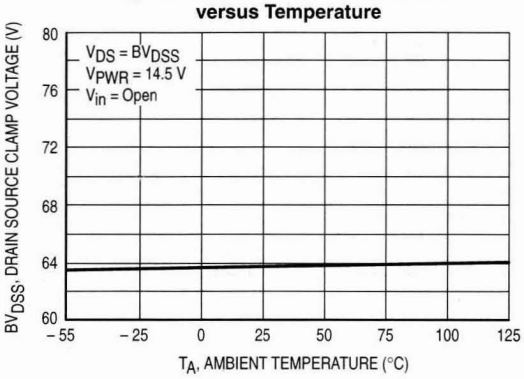


**Figure 10. Zero Input Voltage Drain Current versus Temperature**

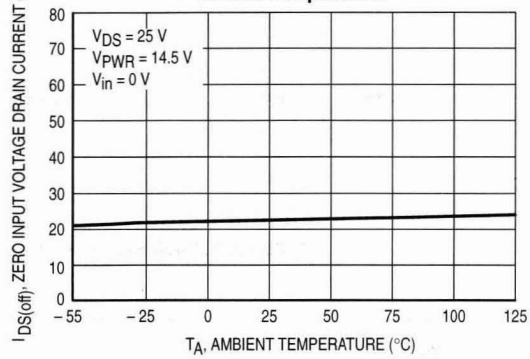


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**Figure 11. Current Limit versus Temperature**

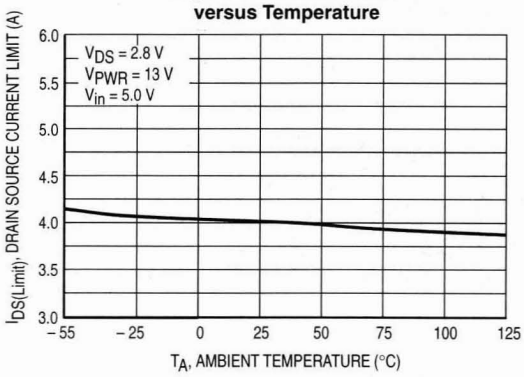
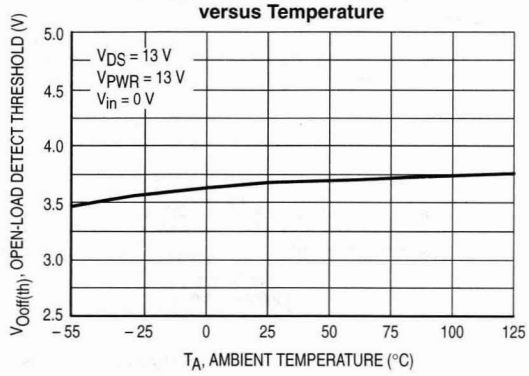



**Figure 12. Open-Load Threshold versus Temperature**



## PIN DESCRIPTION

| Pin | Function | Description |
|---|---|---|
| 1 | Output 2 | This is one of four open drain power MOSFET output connections. The load is connected from this pin to the positive voltage supply. |
| 2 | Output 1 | This is one of four open drain power MOSFET output connections. The load is connected from this pin to the positive voltage supply. |
| 3 | Input 1 | This input controls the turn ON and turn OFF of Output 1 when the $\overline{\text{Single}}$/Dual pin is at a logic low level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 4 | Input 2 | This input controls the turn ON and turn OFF of Output 2 when the $\overline{\text{Single}}$/Dual pin is at a logic low level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 5 | Input 1 & 2 | This input controls the turn ON and turn OFF of Output 1 and Output 2 when the $\overline{\text{Single}}$/Dual select pin is at a logic high level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 6 | $\overline{\text{Single}}$/Dual Select | This input selects between the single (one input controls one output) mode and the dual (one input controls two outputs) mode of operation. |
| 7 | $V_{PWR}$ | The power (voltage and current) to operate the IC is supplied through this pin. The MC33293A is designed to operate over a voltage range of 5.5 V to 30 V. |
| 8 | Ground | IC ground reference pin. |
| 9 | N/C | No connection. |
| 10 | $\overline{\text{Fault}}$ | One of three fault conditions, Output-On Open-Load, Output-Off Open-Load or Over-Current are reported at this output. A logic low state signals the existence of a fault condition. This output has an internal active pull-up and does not require an external pull-up resistor. |
| 11 | Input 3 & 4 | This input controls the turn ON and turn OFF of Output 3 and Output 4 when the $\overline{\text{Single}}$/Dual select pin is at a logic high level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 12 | Input 4 | This input controls the turn ON and turn OFF of Output 4 when the $\overline{\text{Single}}$/Dual pin is at a logic low level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 13 | Input 3 | This input controls the turn ON and turn OFF of Output 3 when the $\overline{\text{Single}}$/Dual pin is at a logic low level. It is a CMOS input with an internal active pull-down employed for noise immunity. |
| 14 | Output 3 | This is one of four open-drain power MOSFET output connections. The load is connected from this pin to the positive voltage supply. |
| 15 | Output 4 | This is one of four open-drain power MOSFET output connections. The load is connected from this pin to the positive voltage supply. |

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## CIRCUIT DESCRIPTION

### Introduction

The MC33293A is a four output low side switch originally intended for use in automotive applications as a fuel injection driver. This circuit can be used in a variety of applications. It is parametrically specified over a battery voltage range of 9.0 V to 14.5 V, but is designed to operate over a considerably wider range of 5.5 V to 30 V. The design incorporates the use of logic level MOSFETs as output devices which are fully enhanced at a gate voltage of 5.0 V, eliminating the need for internal charge pumps. Each output is identically sized and is *independent* in operation. The efficiency of each output device is such that with as little as 9.0 V of $V_{PWR}$ applied, the $R_{DS(on)}$ is 0.18 Ω typically, at room temperature and increases to only 0.22 Ω as $V_{PWR}$ decreases to 5.5 V.

All inputs of the MC33293A are CMOS and have individual 11 μA internal active pull-downs. This eliminates the need for external pull-down resistors to prevent false switching due to noise on the input control lines. This also ensures that at power-up, no load is turned on before a logic high appears on an input pin. Fault reporting is through the use of an open-drain MOSFET having a 100 μA internal active pull-up.

All inputs incorporate *true logic* (or positive logic). This means that whenever an input is in a logic low state (< 0.8 V) the corresponding output will be in an OFF state. Conversely, whenever an input is in a logic high state (> 3.0 V), the corresponding output will be in an ON state.

### $\overline{\text{Single}}$/Dual Select

The $\overline{\text{Single}}$/Dual Select pin can be used to switch between completely independent control and control of the outputs in pairs. Whenever the $\overline{\text{Single}}$/Dual Select pin is in a logic low state, Inputs 1, 2, 3 and 4 control Outputs 1, 2, 3 and 4, respectively. In this mode, only Inputs 1, 2, 3 and 4 can exercise individual control over their respective output. Hence the term "single select" mode of operation. Input 1 & 2 (Pin 5) and Input 3 & 4 (Pin 11) have *no* control whenever the $\overline{\text{Single}}$/Dual Select pin is in a logic low state.

When the $\overline{\text{Single}}$/Dual Select pin is held at a logic high state, Control Inputs 1, 2, 3 and 4 are turned OFF and can *not* exercise any control over the outputs. In this mode, input control transfers from a single to a dual mode of operation, wherein only Input 1 & 2 and Input 3 & 4 have control of Output 1 plus Output 2, and Output 3 plus Output 4, respectively. Hence the term "Dual Select" mode of operation.

### Paralleling Outputs

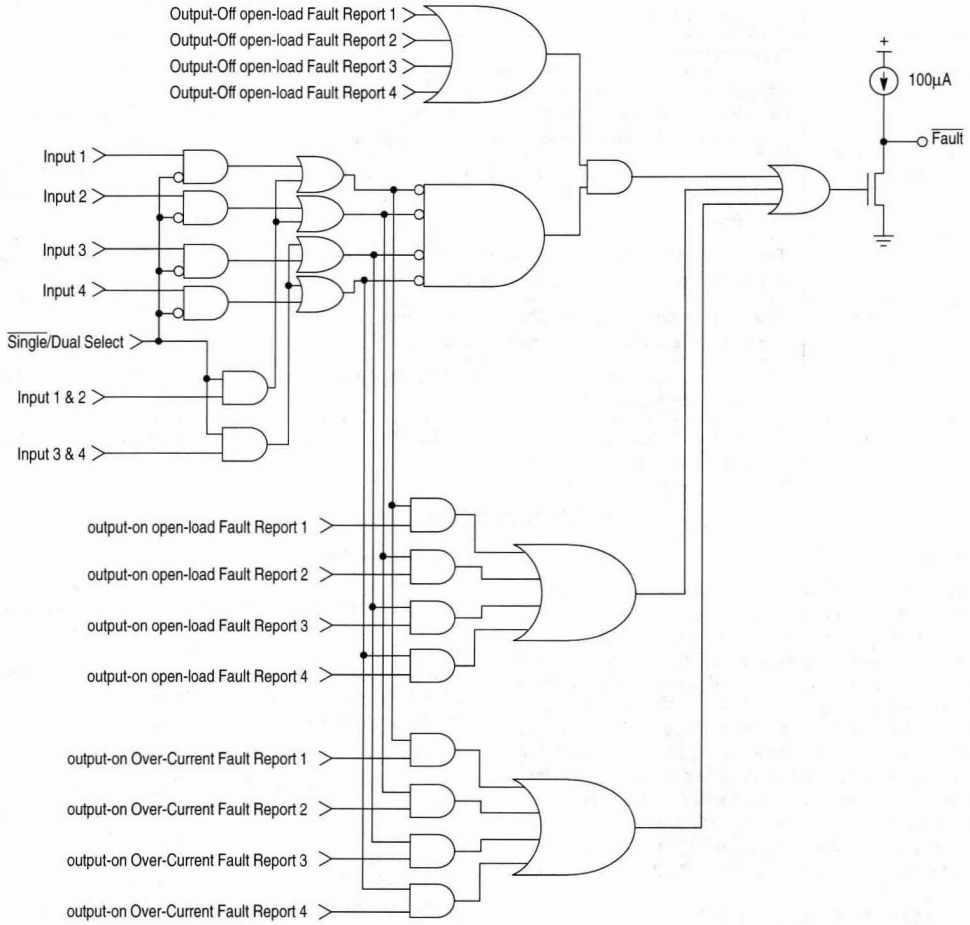
Paralleling outputs may be desirable in the event the application requires a lower $R_{DS(on)}$ or higher current switching capability than a single output. The MC33293A can be operated with all outputs (and therefore all inputs) tied together but modified operation is to be expected. With all inputs tied together and depending on the dual or single select mode used, the paralleled input control current will either be twice (with the dual mode selected) or four times (with the single mode selected) that of any single input. Other expected differences are: $R_{DS(on)}$ will decrease by a factor of four while the Output-On Open-Load Detect current and the Output Limiting current will increase by a factor of four. There will be no change in the Over-Voltage Shutdown Range or the Output-Off Output-On Open-Load Detect Threshold Voltage Range. As always, system level thermal design and verification are important when outputs are paralleled.

## FAULT LOGIC OPERATION

### General

The Fault Status output (Pin 10) on the MC33293A reports any one of three possible faults from any one of the four outputs. The three possible faults are output-on open-load Fault, output-off open-load Fault and over-current Fault. All faults from any of the four outputs are OR'd together and reported by the single Fault Status output-on Pin 10 (Figure 13).

**Figure 13. MC33293A Fault Logic Diagram**

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**Output-On open-load Fault**

The MC33293A always checks for an open-load on the outputs whether the outputs are ON or OFF. An output-on open-load Fault is detected if an open-load exists when the output is ON (corresponding input at a logic high state). The output-on open-load Fault detection occurs when the load current is less than the minimum Output-On Open-Load Detect current ($I_{Oon(th)}$), specified in this data sheet. The value of $I_{Oon(th)}$ is, typically, 75 mA at room temperature. See Figure 3.

The minimum load resistance value that the MC33293A will interpret as an output-on open-load ($R_{open(on)}$) is a function of; the Output-On Open-Load Detect current ($I_{Oon(th)}$); the load supply voltage ($V_{load}$); and the resistance of the output ($R_{DS(on)}$), as shown below.

$$R_{open(on)} = [V_{load} / I_{Oon(th)}] - R_{DS(on)} \approx V_{load} / I_{Oon(th)} \quad (1)$$

Using Equation 1 for the steady state case,
when: $V_{load}$ = 14 V
$R_{DS(on)}$ = 0.3 Ω
$I_{Oon(th)}$ = 75 mA
an output-on open-load Fault will be detected and reported whenever $R_{load} \geq 187\ \Omega$.

Each output has an output-on open-load fault detect circuit that performs real time load current monitoring. Load current is monitored immediately after any output is turned ON. Since it takes a finite amount of time for load current to begin, the MC33293A detects an output-on open-load Fault from the time the output is turned ON until the load current exceeds the Output-On Open-Load Detect current ($I_{Oon(th)}$). It is important to note that a fault will *not* be reported at the Fault Status output during this short period of time. This is due to the built-in output-on open-load Fault Status Delay Time ($t_{oson}$), see Figure 3. This delay time is incorporated in the MC33293A to mask the reporting of a false output-on open-load Fault at the Fault Status output. The delay is typically 2.2 ms.

The purpose for the $t_{os(on)}$ delay is to prevent false fault reporting, especially when driving inductive loads. The load inductance causes a current lag when the load is turned ON. The normal current lag of an inductive load could be misinterpreted as an open-load if it weren't for the built-in delay. This delay or masking is accomplished internally with a single timer which resets every time any input switches from a low-to-high logic state. An output-on open-load Fault will be reported by the Fault Status output as a result of turning ON an output having an open-load Fault and the most recent $t_{os(on)}$ is allowed to lapse after switching ON any input.

The time it takes the load current to reach $I_{Oon(th)}$ is a function of the load resistance ($R_{load}$); load inductance ($L_{load}$); output on resistance ($R_{DS(on)}$); load supply voltage ($V_{load}$); and the turn-on time ($t_{on}$) as shown below. The value of $t_{on}$ is comprised of the low-to-high $V_{in}$ propagation delay time ($t_{on(dly)}$), and the output voltage rise time ($t_r$). See Figure 2.

$$t_{on(false\ fault)} = -\tau \ln [(I_{Oon(th)} - I_{load}) / (-I_{load})] + t_{on} \quad (2)$$

where: $\tau = L_{load} / R_{load}$ = time constant (3)

$$I_{load} = V_{load} / [R_{load} + R_{DS(on)}] \quad (4)$$

$$t_{on} = t_{on(dly)} + t_r \quad (5)$$

Using Equation 2 for the transient case,
when: $V_{load}$ = 14 V
$R_{DS(on)}$ = 0.3 Ω
$L_{load}$ = 10 mH
$R_{load}$ = 14 Ω
$I_{Oon(th)}$ = 75 mA
an output-on open-load Fault will be detected, but not reported after initial turn ON for a duration of 57 µs + $t_{on}$.

**Output-Off open-load Fault**

The MC33293A checks for open-loads on the outputs regardless of an output being on or off. An output-off open-load Fault is detected if an open-load exists when the output is turned OFF (corresponding input at a logic low state). When any one of the four outputs are turned OFF, an independent internal current source tied to each output tries to pull a small amount of zero input voltage drain current ($I_{DS(off)}$, typically 23 µA), through the load. If, while this zero input voltage drain current is being pulled through the load, the output voltage is less than the output-off open-load Detect Threshold Voltage ($V_{Ooff(th)}$, typically 3.7 V), an output-off open-load Fault will be detected.

The zero input voltage drain current could be provided by a large external resistor connected from the output to ground. However, if an external resistor were used to provide this zero input voltage drain current, only "opens" resulting from open-loads or output to ground shorts could be detected. The external resistor could *not* guarantee detection of an open resulting from an output wire bond failure internal to the MC33293A. Because the current source is provided internally, open loads, output to ground shorts, and loss of output wire bonds will all be detected.

The value of load resistance that will be detected as an output-off open-load ($R_{open(off)}$), is a function of the zero input voltage drain current ($I_{DS(off)}$); the load supply voltage ($V_{load}$); and the output-off open-load Detect Threshold Voltage ($V_{Ooff(th)}$), as shown next by:

$$R_{open(off)} = \frac{[V_{load} - V_{Ooff(th)}]}{I_{DS(off)}} \quad (6)$$

Using Equation 6 for the steady state case,
when: $V_{load}$ = 14 V
$I_{DS(off)}$ = 23 µA
$V_{Ooff(th)}$ = 3.7 V
an output-off open-load Fault will be detected and reported whenever $R_L \geq 448\ k\Omega$.

Each output has an output-off open-load fault detect circuit that performs real time output voltage monitoring. Output voltage is monitored immediately after any output is turned off. A finite amount of time is required for output voltage to rise. The MC33293A detects an output-off open-load Fault from when an output is turned off until the output voltage exceeds the output-off open-load Detect Threshold Voltage ($V_{Ooff(th)}$). It is important to note a fault will *not* be reported at the Fault Status output during this rise time. This is due to the built-in output-off open-load Fault Status Delay Time, $t_{os(off)}$, see Figure 4. This delay time is incorporated in the MC33293A to delay the reporting of an output-off open-load Fault at the Fault Status Output. The delay is typically 19 µs.

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The purpose for the $t_{os(off)}$ delay is to prevent false fault reporting experienced with capacitance type loads. The load capacitance causes the rise in output voltage to lag even after the load has been turned OFF. The normal voltage lag caused by load capacitance could be misinterpreted as an open-load if it weren't for the built-in delay. This delay, or masking, is accomplished with four separate timers that reset independent of each other when the corresponding input is switched from a high to a low logic state. Internal logic prevents an output-off open-load Fault from being reported at the Fault pin when any input is high. An output-off open-load Fault will be reported at the Fault Status pin after an open load occurs, all inputs not corresponding to the faulted output are low and a time in excess of $t_{os(off)}$ is exceeded after switching OFF the input corresponding to the faulted output.

*An important note that bears repeating is that an output-off open-load Fault will not be reported at the Fault Status pin unless all input pins are at a logic low state (Figure 13). This is a Fault Status interrogation feature. It helps in distinguishing between an output-on open-load Fault and an output-on over-current Fault.* (Fault Status interrogation is explained in greater detail in a later section).

The time the output voltage takes to reach $V_{Ooff(th)}$ after being turned OFF is $t_{off\ false\ fault}$. It is a function of the load resistance ($R_{load}$); load inductance ($L_{load}$); load current ($I_{load}$); output-on resistance ($R_{DS(on)}$), output capacitance ($C_O$); load supply voltage ($V_{load}$); and the turn OFF time ($t_{off}$). The value of $t_{off}$ is comprised of the $V_{in}$ high-to-low propagation delay time ($t_{off(dly)}$), and the output voltage fall time ($t_f$).

For the case when:

$$1/2\ L_{load}\ (I_{load})^2 >> 1/2\ C_O\ (V_{Ooff(th)})^2 \quad (7)$$

$$t_{off\ false\ fault} = [(C_O\ \Delta V) / I_{load}] + t_{off} \quad (8)$$

where: $$I_{load} = V_{load} / [R_{load} + R_{DS(on)}] \quad (9)$$

$$\Delta V = V_{Ooff(th)} - [I_{load}\ R_{DS(on)}] \quad (10)$$

$$t_{off} = t_{off(dly)} + t_f \quad (11)$$

Using Equation 7 for the transient case,
when: $V_{load} = 14$ V
$R_{DS(on)} = 0.3\ \Omega$
$L_{load} = 10$ mH
$R_{load} = 14\ \Omega$
$C_O = 0.001\ \mu F$
$V_{Ooff(th)} = 3.7$ V

an Output-Off open-load Fault will be detected but not reported after initial turn OFF for a duration of 3.5 ns + $t_{off}$. From Equation 7, the energy stored in the load inductor will be 4.8 mJ. This is much greater than the 68 nJ needed to charge the output capacitance. This allows the use of Equation 8 in determining the false output-off open-load Fault duration following turn OFF because it assures that the output capacitance will be charged by the energy stored in the load inductance.

**Over-Current Fault**

An over-current (short circuit or current limit) Fault is the detection and reporting of any output over-current condition. An over-current condition is defined as a condition where load current exceeds the internal current limit value (typically 4.0 A). An over-current condition activates the current limit circuit. This circuit then sends an analog signal to the gate control circuit, lowering the voltage on the output transistor's gate. Lowering the gate voltage forces the output transistor to transition from the resistive (fully enhanced) mode of operation to the current limit (between fully enhanced and fully OFF) mode.

The actual detection of an over-current condition does not occur at the initial onset of current limit. The onset of current limit causes the voltage on the affected output to increase. The actual Over-Current detection occurs when the output voltage increases and exceeds the over-current Detect Voltage Threshold ($V_{OC(limit)}$, typically 3.7 V), while the corresponding input signal is in a logic high state.

After detection, the reporting of an over-current Fault at the Fault Status output is delayed by a time equal to the over-current Sense Time ($t_{oc}$), see Figures 5 and 6. This delay time is typically 55 µs. If the over-current condition no longer exists after the over-current Sense Time has passed, then no fault is reported. The purpose of the Fault reporting delay is to blank any false faults that might be reported due to high inrush current loads such as incandescent lamps. If the over-current condition still exists after the delay time has passed, then a fault will be reported at the Fault Status output and the affected output is turned OFF.

The Over-Current Sense Time is accomplished internally with four separate timers that reset and start independent of each other whenever a corresponding output is turned ON, either due to the corresponding input turning ON or the completion of the over-current Refresh Time ($t_{ref}$) explained in the next paragraph, (see Figures 5 and 6). An over-current Fault will be reported at the Fault Status output when an over-current condition is detected and a lapse time in excess of $t_{oc}$ is exceeded after turning ON the affected output.

At the same time the over-current Fault is reported, a single internal over-current refresh timer resets, causing *any* over-current outputs to be turned OFF for a duration of $t_{ref}$, typically 3.6 ms. After a time $t_{ref}$, the faulted output(s) will be turned ON again to check if the over-current condition still exists. If the over-current condition still exists, the output(s) will be turned OFF again after a time $t_{oc}$. This periodic retry continues turning ON and OFF over-current loads at a duty cycle of $t_{oc}/(t_{oc} + t_{ref})$ with a period of $t_{oc} + t_{ref}$ until either the input is turned OFF or the over-current condition is removed. Any subsequent over-current conditions will reset and restart the $t_{ref}$ timer.

Detection of an over-current condition coincides with, but does not occur until after the onset of current limit. This allows a specific but small current limit range to go undetected. The factors that determine the value of load resistance causing an over-current condition to be detected are: the Output-Load Current Limit [$I_{DS(limit)}$]; load voltage ($V_{load}$); and the Over-Current Detect Threshold Voltage [$V_{OC(limit)}$] as shown below:

$$R_{load(detect)} = \frac{[V_{load} - V_{OC(limit)}]}{I_{DS(limit)}} \quad (12)$$

The factors that determine the value of load resistance that will cause the onset of current limit are: $I_{DS(limit)}$, $V_{load}$, and $R_{DS(on)}$, as shown below.

$$R_{load(limit)} = [V_{load} / I_{DS(limit)}] - R_{DS(on)} \quad (13)$$

For the case when: $V_{load} = 14$ V
$V_{OC(limit)} = 3.7$ V
$R_{DS(on)} = 0.3\ \Omega$
$I_{DS(limit)} = 4.0$ A

an over-current condition will be detected for any load resistance such that $R_{load} \leq 2.6\ \Omega$. An undetected current limit condition will occur any time $2.6\ \Omega \leq R_{load} \leq 3.2\ \Omega$. Notice that the undetected current limit range is quite small.

**Fault Interrogation**

Even though the MC33293A incorporates a single Fault Status Output pin for reporting three different fault conditions, a real time interrogation routine can be used to determine which one of the three Fault conditions is being reported and which single output is affected.

*An important point to note about Fault interrogation is that only one fault on a single output can be interpreted.* In other woRDS, if more than one over-current or open-load Fault exists among the four outputs, it is *not* possible to distinguish which outputs have a fault and which do not. It is very unlikely, however, that more than one output will be faulted at the same time.

When a Fault is reported, the first step is to determine if it is an over-current or open-load Fault ($R_{load} \geq 447$ kΩ, typical). This is done by taking all the inputs (single or dual) to a logic low state. If the Fault Status resets (changes to a logic high state) after the Fault Status Reset Delay Time ($t_{s(reset)}$, see Figure 4) has lapsed, then an over-current Fault is being reported. If the Fault Status does not reset (remains at a logic low state) after $t_{s(reset)}$ has lapsed, then an open-load Fault ($R_{load} \geq 447$ kΩ, typical) is being reported. This type of interrogation is possible because an output-off open-load Fault can only be reported when all the inputs are in a logic low state.

For an over-current Fault, the next step is to determine which single output is affected. After all inputs are turned OFF and the fault status resets, each input is then turned ON then OFF sequentially. A Fault will again be reported when the input to the corresponding Over-Current output is turned ON and $t_{os(on)}$ has lapsed. If the dual input mode is being used, an over-current Fault can only be interrogated down to the two outputs being driven together.

For an open-load Fault ($R_{load} \geq 447$ kΩ, typical) interrogation, all inputs are turned OFF and the fault status remains set. Each input is then turned ON and OFF sequentially. The Fault status will remain set when the input to the corresponding faulted output is turned ON and $t_{os(on)}$ has lapsed. If the dual input mode is used, an open-load Fault can only be interrogated down to the two outputs driven together.

From the example following Equation 1, the typical value of $R_{open(on)}$ is 187 Ω. From the example following Equation 6, the typical value of $R_{open(off)}$ is 447 kΩ. Therefore, if the load resistance is between 187 Ω and 447 kΩ typically, an output-on open-load Fault will be reported at the Fault Status output but an output-off open-load Fault will not. This condition is referred to as a *soft open fault.* If a soft open fault exists, it is reported at the Fault Status output the same as an over-current Fault except for the reporting delay time. A soft open fault has a reporting delay time of 2.2 ms typically, and an over-current Fault has a reporting delay time of only 55 µs typically, after the input to the faulted output is turned ON.

**Figure 14. Truth Table**

| Conditions of Outputs | Inputs | | | | | | | Outputs | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | $\overline{S/D}$ | 1 & 2 | 3 & 4 | 1 | 2 | 3 | 4 | $\overline{Fault}$ |
| Non-Faulted Operation | L | L | L | L | L | X | X | H | H | H | H | H |
| | L | L | L | H | L | X | X | H | H | H | L | H |
| | L | L | H | L | L | X | X | H | H | L | H | H |
| | L | L | H | H | L | X | X | H | H | L | L | H |
| | L | H | L | L | L | X | X | H | L | H | H | H |
| | L | H | L | H | L | X | X | H | L | H | L | H |
| | L | H | H | L | L | X | X | H | L | L | H | H |
| | L | H | H | H | L | X | X | H | L | L | L | H |
| | H | L | L | L | L | X | X | L | H | H | H | H |
| | H | L | L | H | L | X | X | L | H | H | L | H |
| | H | L | H | L | L | X | X | L | H | L | H | H |
| | H | L | H | H | L | X | X | L | H | L | L | H |
| | H | H | L | L | L | X | X | L | L | H | H | H |
| | H | H | L | H | L | X | X | L | L | H | L | H |
| | H | H | H | L | L | X | X | L | L | L | H | H |
| | H | H | H | H | L | X | X | L | L | L | L | H |
| | X | X | X | X | H | L | L | H | H | H | H | H |
| | X | X | X | X | H | H | L | L | L | H | H | H |
| | X | X | X | X | H | L | H | H | H | L | L | H |
| | X | X | X | X | H | H | H | L | L | L | L | H |
| open-load Fault On Output 1 | L | L | L | L | L | X | X | L | H | H | H | L |
| | H | L | L | L | L | X | X | L | H | H | H | L |
| | L | H | H | H | L | X | X | L | L | L | L | H* |
| | H | H | H | H | L | X | X | L | L | L | L | L |
| | X | X | X | X | H | L | L | L | H | H | H | L |
| | X | X | X | X | H | H | L | L | L | H | H | L |
| | X | X | X | X | H | L | H | L | H | L | L | H* |
| | X | X | X | X | H | H | H | L | L | L | L | L |
| Over-Current Fault On Output 1 | L | L | L | L | L | X | X | H | H | H | H | H |
| | H | L | L | L | L | X | X | H | H | H | H | L |
| | L | H | H | H | L | X | X | H | L | L | L | H |
| | H | H | H | H | L | X | X | H | L | L | L | L |
| | X | X | X | X | H | L | L | H | H | H | H | H |
| | X | X | X | X | H | H | L | H | L | H | H | L |
| | X | X | X | X | H | L | H | H | H | L | L | H |
| | X | X | X | X | H | H | H | H | L | L | L | L |

***NOTE:** All inputs must be a logic low state for an Output-Off open-load Fault to be reported.

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MOTOROLA

# MC33298

# Octal Serial Switch with Serial Peripheral Interface I/O

**OCTAL SERIAL SWITCH (SPI Input/Output)**

**SEMICONDUCTOR TECHNICAL DATA**

The MC33298 is an eight output low side power switch with 8 bit serial input control. The MC33298 is a versatile circuit designed for automotive applications, but is well suited for other environments. The MC33298 incorporates SMARTMOS™ technology, with CMOS logic, bipolar/MOS analog circuitry, and DMOS power MOSFETs. The MC33298 interfaces directly with a microcontroller to control various inductive or incandescent loads. The circuit's innovative monitoring and protection features are: very low standby current, cascadable fault reporting, internal 65 V clamp on each output, output specific diagnostics, and independent shutdown of outputs. The MC33298 is parametrically specified over a temperature range of $-40°C \le T_A \le +125°C$ ambient temperature and $9.0\ V \le V_{PWR} \le 16\ V$ supply. The economical 20 pin DIP and SO–24 wide body surface mount plastic packages make the MC33298 very cost effective.

- Designed to Operate Over Wide Supply Voltages of 5.5 V to 26.5 V
- Interfaces Directly to Microprocessor Using SPI Protocol
- SPI Communication for Control and Fault Reporting
- 8–Bit Serial I/O is CMOS Compatible
- 3.0 A Peak Current Outputs with Maximum $R_{DS(on)}$ of 0.45 Ω at 25°C
- Outputs are Current Limited to 3.0 A to 6.0 A for Driving Incandescent Lamp Loads
- Output Voltages Clamped to 65 V During Inductive Switching
- Maximum Sleep Current ($I_{PWR}$) of 50 μA with $V_{DD} \le 2.0$ V
- Maximum of 4.0 mA $I_{DD}$ During Operation
- Maximum of 2.0 mA $I_{PWR}$ During Operation with All Outputs "On"
- Open Load Detection (Outputs "Off")
- Overvoltage Detection and Shutdown
- Each Output has Independent Over Temperature Detection and Shutdown
- Output Mode Programmable for Sustained Current Limit or Shutdown
- Short Circuit Detect and Shutdown with Automatic Retry for Every Write Cycle
- Serial Operation Guaranteed to 2.0 MHz

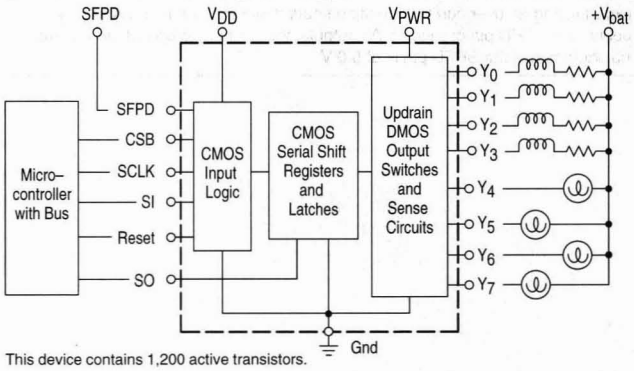
**P SUFFIX**
PLASTIC PACKAGE
CASE 738
DIP (16+2+2)

**DW SUFFIX**
PLASTIC PACKAGE
CASE 751E
SOP (16+4+4)L

**PIN CONNECTIONS**

| DIP | Function | SOP–24L |
|---|---|---|
| 1 | Output 7 | 1 |
| 2 | Output 6 | 2 |
| 3 | SCLK | 3 |
| 4 | SI | 4 |
| 5 | Ground | 5 |
| 6 | Ground | 6 |
| – | Ground | 7 |
| – | Ground | 8 |
| 7 | SO | 9 |
| 8 | CSB | 10 |
| 9 | Output 5 | 11 |
| 10 | Output 4 | 12 |
| 11 | Output 3 | 13 |
| 12 | Output 2 | 14 |
| 13 | SFPD | 15 |
| 14 | $V_{DD}$ | 16 |
| 15 | Ground | 17 |
| 16 | Ground | 18 |
| – | Ground | 19 |
| – | Ground | 20 |
| 17 | $V_{PWR}$ | 21 |
| 18 | Reset | 22 |
| 19 | Output 1 | 23 |
| 20 | Output 0 | 24 |

**Simplified Application**




This device contains 1,200 active transistors.

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC33298P | $T_C = -40°$ to $+125°C$ | DIP |
| MC33298DW | | SOP–24L |

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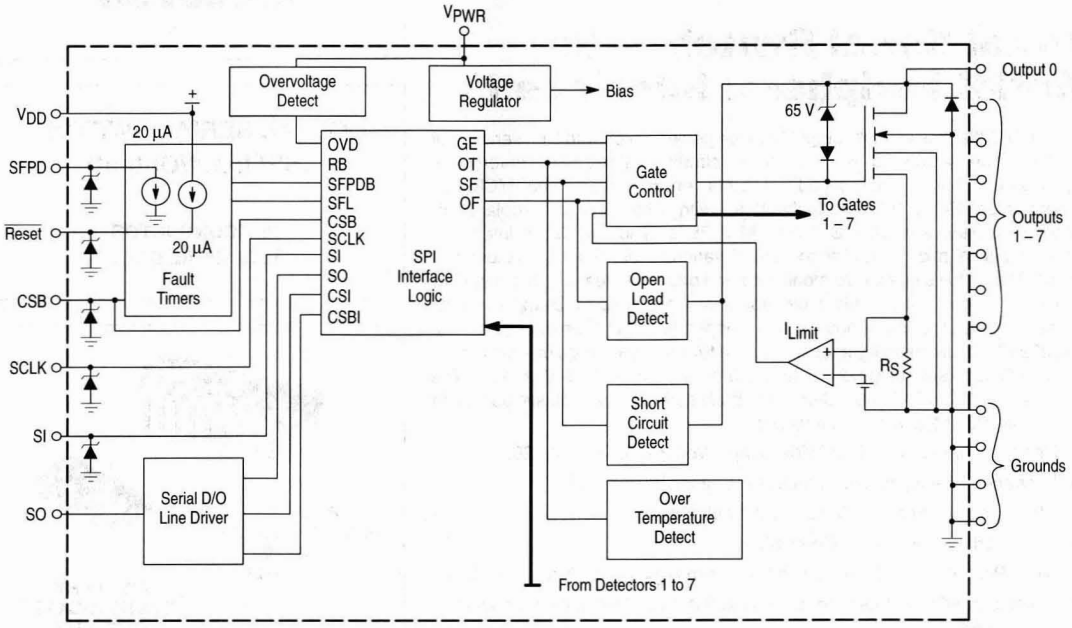
**Figure 1. Simplified Block Diagram**




## FAULT OPERATION

**SERIAL OUTPUT (SO) PIN REPORTS**

| | |
|---|---|
| Overvoltage | Overvoltage condition reported. |
| Over Temperature | Fault reported by Serial Output (SO) pin. |
| Over Current | SO pin reports short to battery/supply or over current condition. |
| Output "On," Open Load Fault | Not reported. |
| Output "Off," Open Load Fault | SO pin reports output "off" open load condition. |

**DEVICE SHUTDOWNS**

| | |
|---|---|
| Overvoltage | Total device shutdown at $V_{PWR}$ = 28–36 V. Re–operates when overvoltage is removed with all outputs assuming an off state upon recovery from overvoltage. All device registers are automatically reset (cleared) during shutdown. |
| Over Temperature | Only the output experiencing an over temperature shuts down. |
| Over Current | Only the output experiencing an over current condition shuts down at 3.0 A to 6.0 A after a 25 µs to 100 µs delay, with SFPD pin grounded. All outputs will continue to operate in a current limit mode, with no shutdown, if the SPFD pin is at 5.0 V. |

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**MAXIMUM RATINGS** (All voltages are with respect to ground, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | | | |
| Steady–State | $V_{PWR(sus)}$ | –1.5 to 26.5 | V |
| Transient Conditions (Note1) | $V_{PWR(pk)}$ | –13 to 60 | V |
| Logic Supply Voltage (Note 2) | $V_{DD}$ | – 0.3 to 7.0 | V |
| Input Pin Voltage (Note 3) | $V_{IN}$ | – 0.3 to 7.0 | V |
| Output Clamp Voltage (Note 4) | $V_{OUT(off)}$ | | V |
| (2.0 mA ≤ $I_{out}$ ≤ 0.5 A) | | 50 to 75 | |
| Output Self–Limit Current | $I_{OUT(lim)}$ | 3.0 to 6.0 | A |
| Continuous Per Output Current (Note 5) | $I_{OUT(cont)}$ | 1.0 | A |
| ESD Voltage | | | |
| Human Body Model (Note 6) | $V_{ESD1}$ | 2000 | V |
| Machine Model (Note 7) | $V_{ESD2}$ | 200 | V |
| Output Clamp Energy (Note 8) | $E_{clamp}$ | | |
| Repetitive: | | | |
| $T_J$ = 25°C | | 100 | mJ |
| $T_J$ = 125°C | | 30 | mJ |
| Non–Repetitive: | | | |
| $T_J$ = 25°C | | 2.0 | J |
| $T_J$ = 125°C | | 0.5 | J |
| Recommended Frequency of SPI Operation (Note 9) | $f_{SPI}$ | 2.0 | MHz |
| Storage Temperature | $T_{stg}$ | – 55 to +150 | °C |
| Operating Case Temperature | $T_C$ | – 40 to +125 | °C |
| Operating Junction Temperature | $T_J$ | – 40 to +150 | °C |
| Power Dissipation ($T_A$ = 25°C) (Note 10) | $P_D$ | 3.0 | W |
| Soldering Temperature (for 10 seconds) | $T_{solder}$ | 260 | °C |
| Thermal Resistance, Junction–to–Ambient (Note 11) | $R_{\theta JA}$ | | °C/W |
| Plastic Package, Case 738: | | | |
| All Outputs "On" (Note 12) | | 31 | |
| Single Output "On" (Note 13) | | 37 | |
| SOP–24 Package, Case 751E: | | | |
| All Outputs "On" (Note 12) | | 34 | |
| Single Output (Note 13) | | 40 | |

**NOTES:**
1. Transient capability with external 100 Ω resistor connected in series with $V_{PWR}$ pin and supply.
2. Exceeding these limits may cause a malfunction or permanent damage to the device.
3. Exceeding voltage limits on SCLK, SI, CSB, SFPD, or Reset pins may cause permanent damage to the device.
4. With output "off."
5. Continuous output rating so long as maximum junction temperature is not exceeded. (See Figure 21 and 22 for more details).
6. ESD1 testing is performed in accordance with the Human Body Model ($C_{Zap}$ = 100 pF, $R_{Zap}$ = 1500 Ω).
7. ESD2 testing is performed in accordance with the Machine Model ($C_{Zap}$ = 100 pF, $R_{Zap}$ = 0 Ω).
8. Maximum output clamp energy capability at indicated Junction Temperature using single pulse method. See Figure 19 for more details.
9. Guaranteed and production tested for 2.0 MHz SPI operation but has been demonstrated to operate to 8.5 MHz @ 25°C.
10. Maximum power dissipation at indicated junction temperature with no heat sink used. See Figures 20, 21, and 22 for more details.
11. See Figure 20 for Thermal Model.
12. Thermal resistance from Junction–to–Ambient with all outputs "on" and dissipating equal power.
13. Thermal resistance from Junction–to–Ambient with a single output "on."

**STATIC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions of 4.5 V ≤ $V_{DD}$ ≤ 5.5 V, 9.0 V ≤ $V_{PWR}$ ≤ 16 V, – 40°C ≤ $T_C$ ≤ 125°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER INPUT** | | | | | |
| Supply Voltage Range | | | | | V |
| Quasi–Functional (Note 1) | $V_{PWR(qf)}$ | 5.5 | – | 9.0 | |
| Full Operational | $V_{PWR(fo)}$ | 9.0 | – | 26.5 | |
| Supply Current (all Outputs "On," $I_{out}$ = 0.5 A) (Note 2) | $I_{PWR(on)}$ | – | 1.0 | 2.0 | mA |
| Sleep State Supply Current ($V_{DD}$ = 0.5 V) | $I_{PWR(ss)}$ | – | 1.0 | 50 | µA |
| Sleep State Output Leakage Current (per Output, $V_{DD}$ = 0.5 V) | $I_{OUT(ss)}$ | – | – | 50 | µA |
| Overvoltage Shutdown | $V_{OV}$ | 28 | – | 36 | V |
| Overvoltage Shutdown Hysteresis | $V_{OV(hys)}$ | 0.2 | – | 1.5 | V |
| Logic Supply Voltage | $V_{DD}$ | 4.5 | – | 5.5 | V |
| Logic Supply Current (with any combination of Outputs "On") | $I_{DD}$ | – | – | 4.0 | mA |
| Logic Supply Undervoltage Lockout Threshold (Note 3) | $V_{DD(uvlo)}$ | 2.0 | – | 4.5 | V |
| **POWER OUTPUT** | | | | | |
| Drain–to–Source "On" Resistance ($I_{out}$ = 0.5 A, $T_J$ = 25°C) | $R_{DS(on)}$ | | | | Ω |
| $V_{PWR}$ = 5.5 V | | – | – | 1.0 | |
| $V_{PWR}$ = 9.0 V | | – | 0.4 | 0.5 | |
| $V_{PWR}$ = 13 V | | – | 0.35 | 0.45 | |
| Drain–to–Source "On" Resistance ($I_{out}$ = 0.5 A, $T_J$ = 150°C) | $R_{DS(on)}$ | | | | Ω |
| $V_{PWR}$ = 5.5 V | | – | – | 1.8 | |
| $V_{PWR}$ = 9.0 V | | – | 0.75 | 0.9 | |
| $V_{PWR}$ = 13 V | | – | 0.65 | 0.8 | |
| Output Self–Limiting Current | $I_{OUT(lim)}$ | | | | A |
| Outputs Programmed "On", $V_{out}$ = 0.6 $V_{DD}$ | | 3.0 | 4.0 | 6.0 | |
| Output Fault Detect Threshold (Note 4) | $V_{OUTth(F)}$ | | | | $V_{DD}$ |
| Output Programmed "Off" | | 0.6 | 0.7 | 0.8 | |
| Output "Off" Open Load Detect Current (Note 5) | $I_{OCO}$ | | | | µA |
| Output Programmed "Off," $V_{out}$ = 0.6 $V_{DD}$ | | 30 | 50 | 100 | |
| Output Clamp Voltage | $V_{OK}$ | | | | V |
| 2.0 mA ≤ $I_{out}$ ≤ 200 mA | | 50 | 60 | 75 | |
| Output Leakage Current ($V_{DD}$ ≤ 2.0 V) (Note 6) | $I_{OUT(lkg)}$ | – 50 | 0 | 50 | µA |
| Over Temperature Shutdown (Outputs "Off") (Note 7) | $T_{LIM}$ | 155 | 170 | 185 | °C |
| Over Temperature Shutdown Hysteresis (Note 7) | $T_{LIM(hys)}$ | – | 10 | 20 | °C |

**NOTES:** 1. SPI inputs and outputs operational; Fault reporting may not be fully operational within this voltage range.
2. Value reflects normal operation (no faults) with all outputs "on." Each "on" output contributes approximately 20 µA to $I_{PWR}$. Each output experiencing a "soft short" condition contributes approximately 0.5 mA to $I_{PWR}$. A "soft short" is defined as any load current causing the output source current to self–limit. A "hard" output short is a very low impedance short to supply.
3. For $V_{DD}$ less than the Undervoltage Lockout Threshold voltage, all data registers are reset and all outputs are disabled.
4. Output fault detect threshold with outputs programmed "off." Output fault detect thresholds are the same for output opens and shorts.
5. Output "Off" Open Load Detect Current is the current required to flow through the load for the purpose of detecting the existence of an open condition when the specific output is commanded to be "off."
6. Output leakage current measured with output "off" and at 16 V.
7. This parameter is guaranteed by design but is not production tested.

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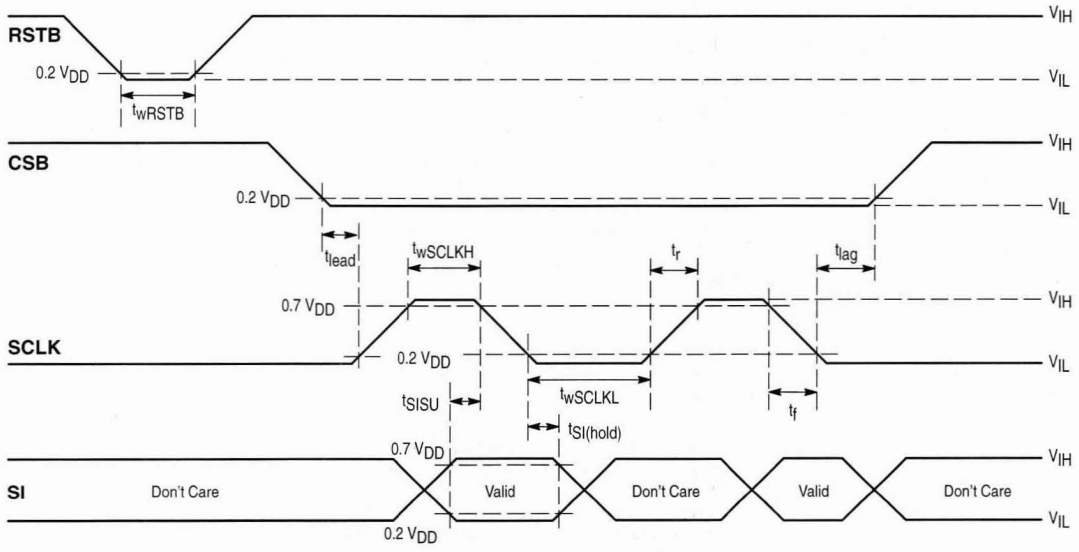
**STATIC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions of 4.5 V ≤ $V_{DD}$ ≤ 5.5 V, 9.0 V ≤ $V_{PWR}$ ≤ 16 V, – 40°C ≤ $T_C$ ≤ 125°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DIGITAL INTERFACE** | | | | | |
| Input Logic High Voltage (Note 1) | $V_{IH}$ | 0.7 | – | 1.0 | $V_{DD}$ |
| Input Logic Low Voltage (Note 2) | $V_{IL}$ | 0.0 | – | 0.2 | $V_{DD}$ |
| Input Logic Voltage Hysteresis (Note 3) | $V_{I(hys)}$ | 50 | 100 | 500 | mV |
| Input Logic Current (Note 4) | $I_{IN}$ | –10 | 0 | 10 | µA |
| Reset Pull–Up Current (Reset = 0.7 $V_{DD}$) | $I_{RSTB}$ | 10 | 22 | 50 | µA |
| SFPD Pull–Down Current (SFPD = 0.2 $V_{DD}$) | $I_{SFPD}$ | 10 | 22 | 50 | µA |
| SO High State Output Voltage ($I_{OH}$ = 1.0 mA) | $V_{SOH}$ | $V_{DD}$ –1.0 V | $V_{DD}$ – 0.6 V | – | V |
| SO Low State Output Voltage ($I_{OL}$ = –1.6 mA) | $V_{SOL}$ | – | 0.2 | 0.4 | V |
| SO Tri–State Leakage Current (CSB = 0.7 $V_{DD}$, 0 V ≤ $V_{SO}$ ≤ $V_{DD}$) | $I_{SOT}$ | – 10 | 0 | 10 | µA |
| Input Capacitance (0 V ≤ $V_{DD}$ ≤ 5.5 V) (Note 5) | $C_{IN}$ | – | – | 12 | pF |
| SO Tri–State Capacitance (0 V ≤ $V_{DD}$ ≤ 5.5 V) (Note 6) | $C_{SOT}$ | – | – | 20 | pF |

**NOTES:** 1. Upper logic threshold voltage range applies to SI, CSB, SCLK, Reset, and SFPD input signals.
2. Lower logic threshold voltage range applies to SI, CSB, SCLK, Reset, and SFPD input signals.
3. Only the SFPD and Reset inputs have hysteresis. This parameter is guaranteed by design but is not production tested.
4. Input current of SCLK, SI, and CSB logic control inputs.
5. Input capacitance of SI, CSB, SCLK, Reset, and SFPD for 0 V ≤ $V_{DD}$ ≤ 5.5 V. This parameter is guaranteed by design, but is not production tested.
6. Tri–state capacitance of SO for 0 V ≤ $V_{DD}$ ≤ 5.5 V. This parameter is guaranteed by design but is not production tested.

**Figure 2. Input Timing Switch Characteristics**

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**DYNAMIC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions of 4.5 V ≤ $V_{DD}$ ≤ 5.5 V, 9.0 V ≤ $V_{PWR}$ ≤ 16 V, – 40°C ≤ $T_C$ ≤ 125°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **POWER OUTPUT TIMING** | | | | | |
| Output Rise Time ($V_{PWR}$ = 13 V, $R_L$ = 26 Ω) (Note 1) | $t_r$ | 0.4 | 1.5 | 20 | µs |
| Output Fall Time ($V_{PWR}$ = 13 V, $R_L$ = 26 Ω) (Note 1) | $t_f$ | 0.4 | 2.5 | 20 | µs |
| Output Turn "On" Delay Time ($V_{PWR}$ = 13 V, $R_L$ = 26 Ω) (Note 2) | $t_{dly(on)}$ | 1.0 | 5.0 | 15 | µs |
| Output Turn "Off" Delay Time ($V_{PWR}$ = 13 V, $R_L$ = 26 Ω) (Note 3) | $t_{dly(off)}$ | 1.0 | 5.0 | 15 | µs |
| Output Short Fault Disable Report Delay (Note 4)<br>SFPD = 0.2 x $V_{DD}$ | $t_{dly(sf)}$ | 25 | 50 | 100 | µs |
| Output "Off" Fault Report Delay (Note 5)<br>SFPD = 0.2 x $V_{DD}$ | $t_{dly(off)}$ | 25 | 50 | 100 | µs |

**NOTES:** 1. Output Rise and Fall time respectively measured across a 26 Ω resistive load at 10% to 90% and 90% to 10% voltage points.
2. Output Turn "On" Delay time measured from rising edge of CSB to 50% of output "off" $V_{out}$ voltage with $R_L$ = 26 Ω resistive load (see Figure 7 and 9).
3. Output Turn "Off" Delay time measured from rising edge of CSB to 50% of output "off" $V_{out}$ voltage with $R_L$ = 26 Ω resistive load (see Figure 7 and 9).
4. Output Short Fault Disable Report Delay measured from rising edge of CSB to $I_{out}$ = 2.0 A point with output "on," $V_{out}$ = 5.0 V, and SFPD = 0.2 x $V_{DD}$ (see Figure 8 and 10).
5. Output "Off" Fault Report Delay measured from 50% points of rising edge of CSB to rising edge of output (see Figure 9).

**DYNAMIC ELECTRICAL CHARACTERISTICS** (Characteristics noted under conditions of 4.5 V ≤ $V_{DD}$ ≤ 5.5 V, 9.0 V ≤ $V_{PWR}$ ≤ 16 V, – 40°C ≤ $T_C$ ≤ 125°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **DIGITAL INTERFACE TIMING** | | | | | |
| SCLK Clock Period (Note 6) | $t_{pSCLK}$ | 500 | – | – | ns |
| SCLK Clock High Time | $t_{wSCLKH}$ | 175 | – | – | ns |
| SCLK Clock Low Time | $t_{wSCLKL}$ | 175 | – | – | ns |
| Required Low State Duration for Reset ($V_{IL}$ ≤ 0.2 $V_{DD}$) (Note 1) | $t_{wRSTB}$ | 250 | 50 | – | ns |
| Falling Edge of CSB to Rising Edge of SCLK (Required Setup Time) | $t_{lead}$ | 250 | 50 | – | ns |
| Falling Edge of SCLK to Rising Edge of CSB (Required Setup Time) | $t_{lag}$ | 250 | 50 | – | ns |
| SI to Falling Edge of SCLK (Required Setup Time) | $t_{SISU}$ | 125 | 25 | – | ns |
| Falling Edge of SCLK to SI (Required Hold Time) | $t_{SI(hold)}$ | 125 | 25 | – | ns |
| SO Rise Time ($C_L$ = 200 pF) | $t_{rSO}$ | – | 25 | 75 | ns |
| SO Fall Time ($C_L$ = 200 pF) | $t_{fSO}$ | – | 25 | 75 | ns |
| SI, CSB, SCLK Incoming Signal Rise Time (Note 2) | $t_{rSI}$ | – | – | 200 | ns |
| SI, CSB, SCLK Incoming Signal Fall TIme (Note 2) | $t_{fSI}$ | – | – | 200 | ns |
| Time from Falling Edge of CSB to SO<br>Low Impedance (Note 3)<br>HIgh Impedance (Note 4) | <br>$t_{SO(en)}$<br>$t_{SO(dis)}$ | <br>–<br>– | <br>–<br>– | <br>200<br>200 | ns |
| Time from Rising Edge of SCLK to SO Data Valid (Note 5)<br>0.2 $V_{DD}$ ≤ SO ≥ 0.8 $V_{DD}$, $C_L$ = 200 pF | $t_{valid}$ | – | 50 | 125 | ns |

**NOTES:** 1. Reset Low duration measured with outputs enabled and going to "off" or disabled condition.
2. Rise and Fall time of incoming SI, CSB, and SCLK signals suggested for design consideration to prevent the occurrence of double pulsing.
3. Time required for output status data to be available for use at SO.
4. Time required for output status data to be terminated at SO.
5. Time required to obtain valid data out from SO following the rise of SCLK.
6. Clock period includes 75 ns rise plus 75 ns fall transition time in addition to clock high and low time.

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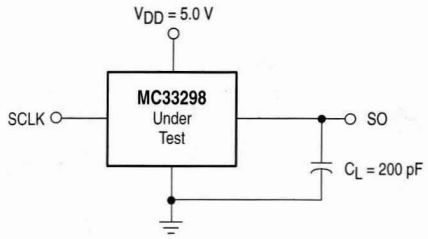
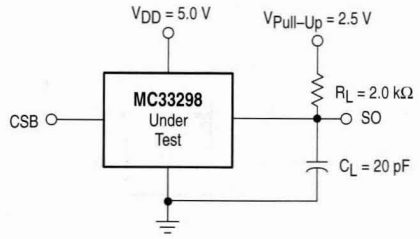
**Figure 3. Valid Data Delay Time and Valid Time Test Circuit**



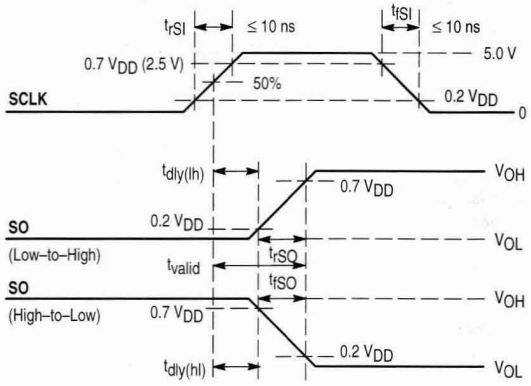

$C_L$ represents the total capacitance of the test fixture and probe.

**Figure 4. Enable and Disable Time Test Circuit**



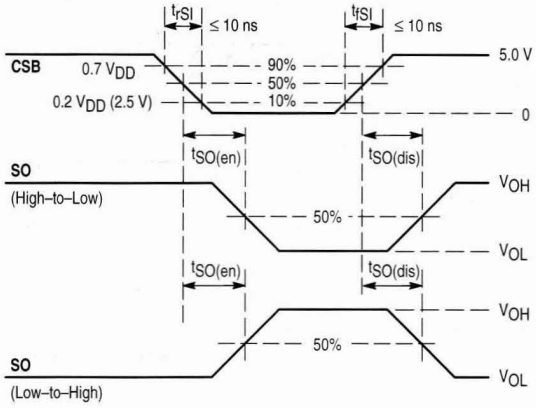

$C_L$ represents the total capacitance of the test fixture and probe.

**Figure 5. Vaild Data Delay Time and Valid Time Waveforms**




SO (low–to–high) is for an output with internal conditions such that the low–to–high transition of CSB causes the SO output to switch from high–to–low.

**Figure 6. Enable and Disable Time Waveforms**




**NOTES**: 1. SO (high–to–low) waveform is for SO output with internal conditions such that SO output is low except when an output is disabled as a result of detecting a circuit fault with CSB in a High Logic state (e.g., open load).
2. SO (low–to–high) waveform is for SO output with internal conditions such that SO output is high except when an output is disabled as a result of detecting a circuit fault with CSB in a High Logic state (e.g., shorted load).

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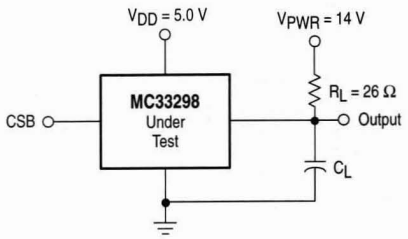
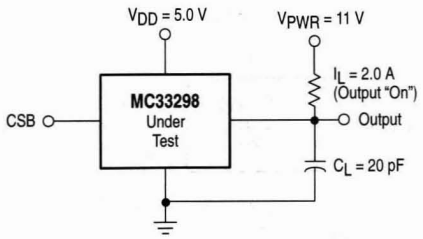
**Figure 7. Switching Time Test Circuit**



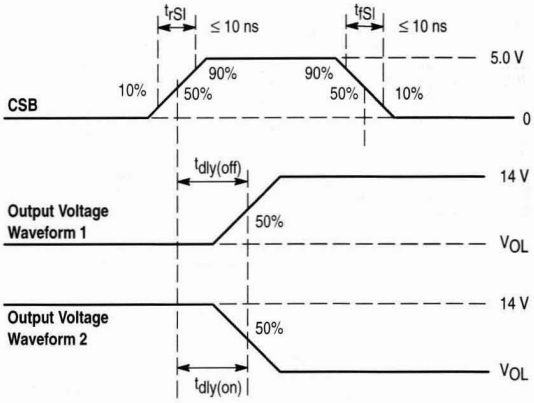

$C_L$ represents the total capacitance of the test fixture and probe.

**Figure 8. Output Fault Unlatch Disable Delay Test Circuit**



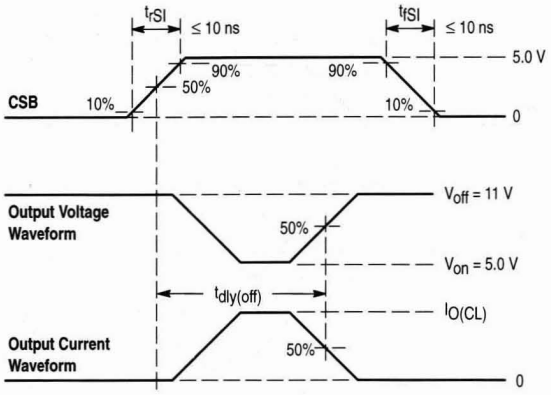

$C_L$ represents the total capacitance of the test fixture and probe.

**Figure 9. Turn–On/Off Waveforms**




**NOTES**: 1. $t_{dly(on)}$ and $t_{dly(off)}$ are turn–on and turn–off propagation delay times.
2. Waveform 1 is an output programmed from an "on" to an "off" state.
3. Waveform 2 is an output programmed from an "off" to an "on" state.

**Figure 10. Output Fault Unlatch Disable Delay Waveforms**




**NOTES**: 1. $t_{pdly(off)}$ is the output fault unlatch disable propagation delay time required to correctly report an output fault after CSB rises. Represents an output commanded "on" while having an existing output short (overcurrent) to supply.
2. SFPD pin ≤ 0.2 V.

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## CIRCUIT DESCRIPTION

### Introduction

The MC33298 was conceived, specified, designed, and developed for automotive applications. It is an eight output low side power switch having 8–bit serial control. The MC33298 incorporates SMARTMOS™ technology having effective 2.0 μ CMOS logic, bipolar/MOS analog circuitry, and independent state of the art double diffused MOS (DMOS) power output transistors. Many benefits are realized as a direct result of using this mixed technology. A simplified block diagram of the MC33298 is shown in Figure 1.

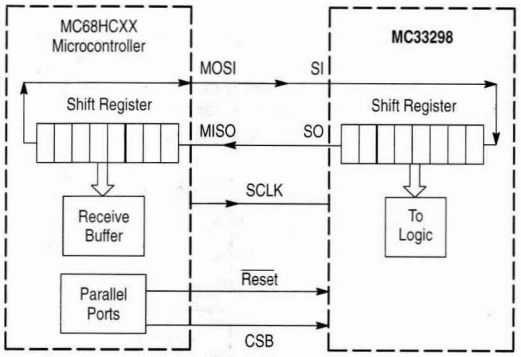
Where bipolar devices require considerable control current for their operation, structured MOS devices, since they are voltage controlled, require only transient gate charging current affording a significant decrease in power consumption. The CMOS capability of the SMARTMOS™ process allows significant amounts of logic to be economically incorporated into the monolithic design. In addition, bipolar/MOS analog circuits embedded within the updrain power DMOS output transistors monitor and provide fast, independent protection control functions for each individual output. All outputs have internal 65 V at 0.5 A independent output voltage clamps to provide fast inductive turn–off and transient protection.

The MC33298 uses high efficiency updrain power DMOS output transistors exhibiting very low drain to source "on" resistance values ($R_{DS(on)} \leq 0.45\ \Omega$) and dense CMOS control logic. Operational bias currents of less than 4.0 mA (1.0 mA typical) with any combination of outputs "on" are the result of using this mixed technology and would not be possible with bipolar structures. To accomplish a comparable functional feature set using a bipolar structure approach would result in a device requiring hundreds of milliamperes of internal bias and control current. This would represent a very large amount of power to be consumed by the device itself and not available for load use.

In operation the MC33298 functions as an eight output serial switch serving as a microcontroller (MCU) bus expander and buffer with fault management and fault reporting features. In doing so, the device directly relieves the MCU of the fault management functions. The MC33298 directly interfaces to an MCU and operates at system clock serial frequencies in excess of 2.0 MHz using a Synchronous Peripheral Interface (SPI) for control and diagnostic readout.

Figure 11 shows the basic SPI configuration between an MCU and one MC33298.

**Figure 11. SPI Interface with Microcontroller**




The circuit can also be used in a variety of other applications in the computer, telecommunications, and industrial fields. It is parametrically specified over an input "battery"/supply range of 9.0 V to 16 V but is designed to operate over a considerably wider range of 5.5 V to 26.5 V. The design incorporates the use of Logic Level MOSFETs as output devices. These MOSFETs are sufficiently turned "on" with a gate voltage of less than 5.0 V thus eliminating the need for an internal charge pump. Each output is identically sized and independent in operation. The efficiency of each output transistor is such that with as little as 9.0 V supply ($V_{PWR}$), the maximum $R_{DS(on)}$ of an output at room temperature is 0.45 Ω (0.35 Ω typical) and increases to only 1.0 Ω (0.5 Ω typical) as $V_{PWR}$ is decreased to 5.5 V.

All inputs are compatible with 5.0 V CMOS logic levels and incorporate negative or inverted logic. Whenever an input is programmed to a logic low state (< 1.0 V) the corresponding low side switched output being controlled will be active low and turned "on." Conversely, whenever an input is programmed to a logic high state (> 3.0 V), the output being controlled will be high and turned "off."

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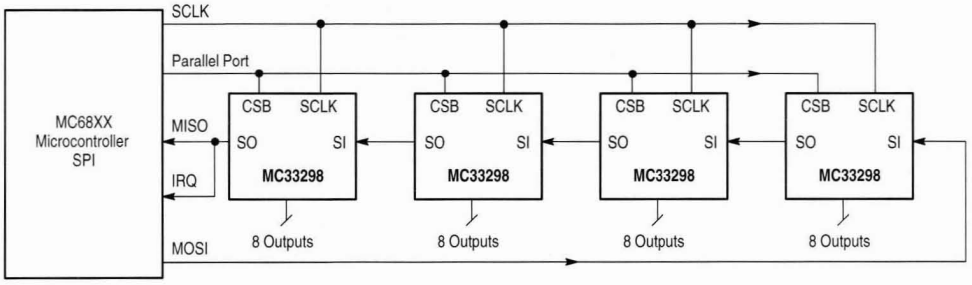
**Figure 12. MC33298 SPI System Daisy Chain**



One main advantage of the MC33298 is the serial port which when coupled to an MCU, receives "on"/"off" commands from the MCU and in return transmits the drain status of the device's output switches. Many devices can be "daisy–chained" together to form a larger system (see Figure 12). Note in this example that only one dedicated MCU parallel port (aside from the required SPI) is needed for chip select to control 32 possible loads.

Multiple MC33298 devices can also be controlled in a parallel input fashion using SPI (see Figure 13). This figure shows a possible 24 loads being controlled by only three dedicated parallel MCU ports used for chip select.

**Figure 13. Parallel Input SPI Control**

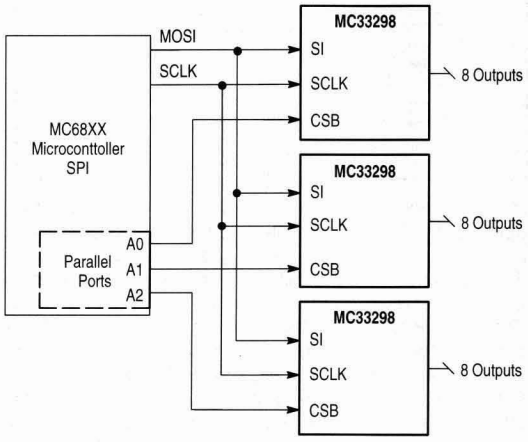



Figure 14 shows a basic method of controlling multiple MC33298 devices using two MCUs. A system can have only one master MCU at any given instant of time and one or more slave MCUs. The master MCU supplies the system clock signal (top MCU designated the master); the lower MCU being the slave. It is possible to have a system with more than one master but not at the same time. Only when the master is not communicating can a slave communicate. MCU master control is switched through the use of the slave select ($\overline{SS}$) pin of the MCUs. A master will become a slave when it detects a logic low state on its $\overline{SS}$ pin.

These basic examples make the MC33298 very attractive for applications where a large number of loads need be controlled efficiently. The popular Synchronous Serial Peripheral Interface (SPI) protocol is incorporated, to this end, to communicate efficiently with the MCU.

**SPI System Attributes**

The SPI system is flexible enough to communicate directly with numerous standard peripherals and MCUs available from Motorola and other semiconductor manufacturers. SPI reduces the number of pins necessary for input/output (I/O) on the MC33298. It also offers an easy means of expanding the I/O function using few MCU pins. The SPI system of communication consists of the MCU transmitting, and in return, receiving one databit of information per clock cycle.

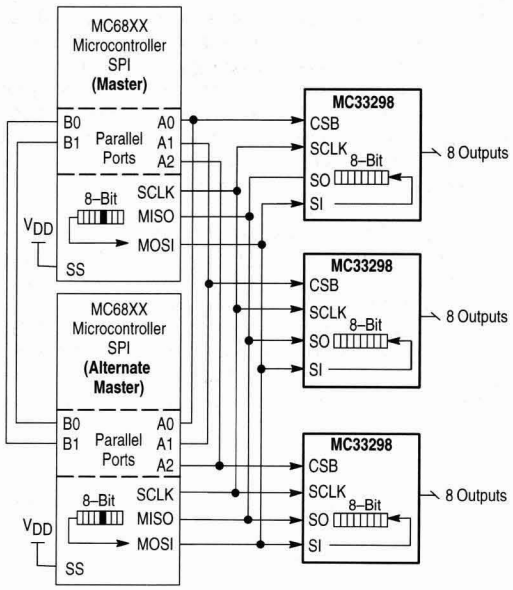
Databits of information are simultaneously transmitted by one pin, Microcontroller Out Serial In (MOSI), and received by another pin, Microcontroller In Serial Out (MISO), of the MCU.

Some features of SPI are:

- Full Duplex, Three–Wire Synchronous Data Transfer
- Each Microcontroller can be a Master or a Slave
- Provides Write Collision Flag Protection
- Provides End of Message Interrupt Flag
- Four I/Os associated with SPI (MOSI, MISO, SCLK, SS)

The only drawbacks to SPI are that an MCU is required for efficient operational control and, in contrast to parallel input control, is slower at performing pulse width modulating (PWM) functions.

**Figure 14. Multiple MCU SPI Control**



## PIN FUNCTION DESCRIPTION

### CSB Pin

The system MCU selects the MC33298 to be communicated with through the use of the CSB pin. Whenever the pin is in a logic low state, data can be transferred from the MCU to the MC33298 and vise versa. Clocked–in data from the MCU is transferred from the MC33298 shift register and latched into the power outputs on the rising edge of the CSB signal. On the falling edge of the CSB signal, drain status information is transferred from the power outputs and loaded into the device's shift register. The CSB pin also controls the output driver of the serial output pin. Whenever the CSB pin goes to a logic low state, the SO pin output driver is enabled allowing information to be transferred from the MC33298 to the MCU. To avoid any spurious data, it is essential that the high–to–low transition of the CSB signal occur only when SCLK is in a logic low state.

### SCLK Pin

The system clock pin (SCLK) clocks the internal shift registers of the MC33298. The serial input pin (SI) accepts data into the input shift register on the falling edge of the SCLK signal while the serial output pin (SO) shifts data information out of the shift register on the rising edge of the SCLK signal. False clocking of the shift register must be avoided to guarantee validity of data. It is essential that the SCLK pin be in a logic low state whenever chip select bar pin (CSB) makes any transition. For this reason, it is recommended though not necessary, that the SCLK pin be kept in a low logic state as long as the device is not accessed (CSB in logic high state). When CSB is in a logic high state, any signal at the SCLK and SI pin is ignored and SO is tristated (high impedance). See the Data Transfer Timing diagram of Figure 16.

### SI Pin

This pin is for the input of serial instruction data. SI information is read in on the falling edge of SCLK. A logic high state present on this pin when the SCLK signal rises will program a specific output "off," and in turn, turns "off" the specific output on the rising edge of the CSB signal. Conversely, a logic low state present on the SI pin will program the output "on," and in turn, turns "on" the specific output on the rising edge of the CSB signal. To program the eight outputs of the MC33298 "on" or "off," an eight bit serial stream of data is required to be entered into the SI pin starting with Output 7, followed by Output 6, Output 5, etc., to Output 0. For each rise of the SCLK signal, with CSB held in a logic low state, a databit instruction ("on" or "off") is loaded into the shift register per the databit SI state. The shift register is full after eight bits of information have been entered. To preserve data integrity, care should be taken to not transition SI as SCLK transitions from a low to high logic state.

### SO Pin

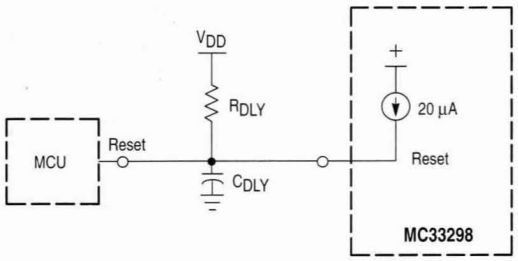
The serial output (SO) pin is the tri–stateable output from the shift register. The SO pin remains in a high impedance state until the CSB pin goes to a logic low state. The SO data reports the drain status, either high or low. The SO pin changes state on the rising edge of SCLK and reads out on the falling edge of SCLK. When an output is "off" and not faulted, the corresponding SO databit is a high state. When an output is "on," and there is no fault, the corresponding databit on the SO pin will be a low logic state. The SI/SO shifting of data follows a first–in–first–out protocol with both input and output words transferring the Most Significant Bit (MSB) first. The SO pin is not affected by the status of the Reset pin.

### Reset Pin

The MC33298 Reset pin is active low and used to clear the SPI shift register and in doing so sets all output switches "off." With the device in a system with an MCU; upon initial system power up, the MCU holds the Reset pin of the device in a logic low state ensuring all outputs to be "off" until both the $V_{DD}$ and $V_{PWR}$ pin voltages are adequate for predictable operation. After the MC33298 is reset, the MCU is ready to assert system control with all output switches initially "off." If the $V_{PWR}$ pin of the MC33298 experiences a low voltage, following normal operation, the MCU should pull the Reset pin low so as to shutdown the outputs and clear the input data register. The Reset pin is active low and has an internal pull–up incorporated to ensure operational predictability should the external pull–up of the MCU open circuit. The internal pull–up is only 20 μA to afford safe and easy interfacing to the MCU. The Reset pin of the MC33298 should be pulled to a logic low state for a duration of at least 250 ns to ensure reliable reset.

A simple power "on" reset delay of the system can be programmed through the use of an RC network comprised of a shunt capacitor from the Reset pin to Ground and a resistor to $V_{DD}$ (See Figure 15). Care should be exercised to ensure proper discharge of the capacitor so as to not adversely delay the reset nor damage the MCU should the MCU pull the Reset line low and yet accomplish initialization for turn "on" delay. It may be easier to incorporate delay into the software program and use a parallel port pin of the MCU to control the MC33298 Reset pin.

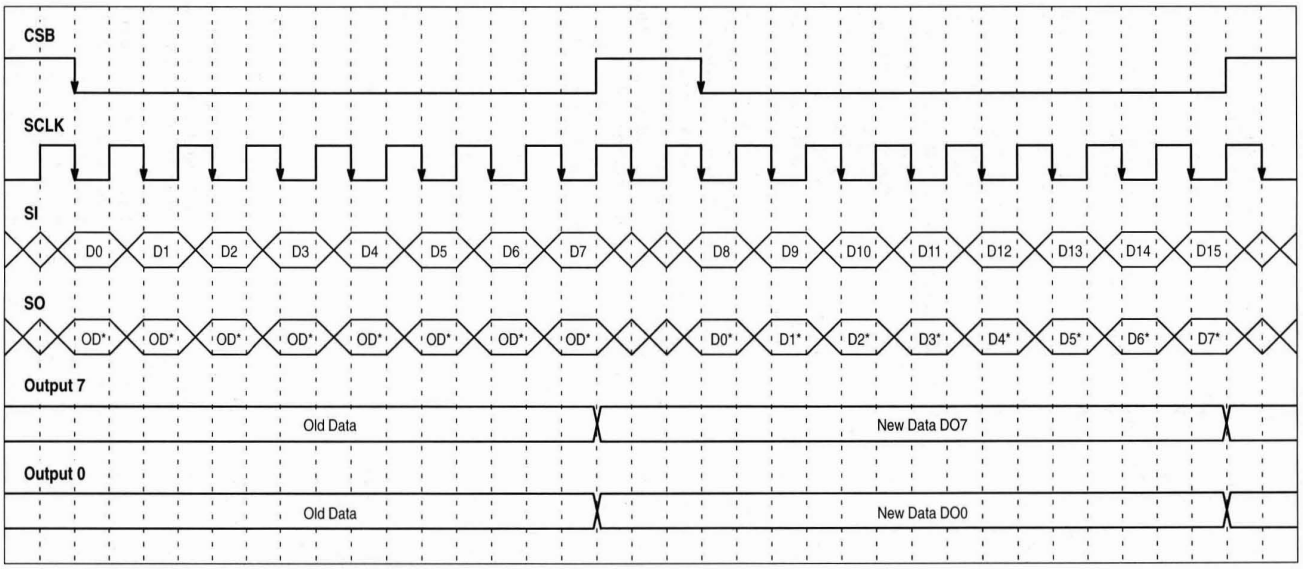
**Figure 15. Power "On" Reset**




### SFPD Pin

The Short Fault Protect Disable (SFPD) pin is used to disable the over current latch–off. This feature allows control of incandescent loads where in–rush currents exceed the device's analog current limits. Essentially the SFPD pin determines whether the MC33298 output(s) will instantly shut down upon sensing an output short or remain "on" in a current limiting mode of operation until the output short is removed or thermal shutdown is reached. If the SFPD pin is tied to $V_{DD}$ = 5.0 V the MC33298 output(s) will remain "on" in a current limited mode of operation upon encountering a load short to supply. If the SFPD pin is grounded, a short circuit will immediately shut down only the output affected. Other outputs not having a fault condition will operate normally. The short circuit operation is addressed in more detail later.

**Figure 16. Data Transfer Timing**




**NOTES:** 1. $\overline{\text{Reset}}$ pin is in a logic high state during the above operation.
2. D0, D1, D2, ..., and D15 relate to the ordered entry of program data into the MC33298 with D0/D8 bits (MSB) corresponding to Output 7 and D7/D15 corresponding to Output 0.
3. D0*, D1*, D2*, ..., and D7* relate to the ordered data out of the MC33298 with D0* bit (MSB) corresponding to Output 7.
4. OD* corresponds to Old Databits.
5. For brevity, only DO7 and DO0 are shown which respectively correspond to Output 7 and Output 0.

**Data Transfer Timing (General)**

| | |
|---|---|
| CSB High–to–Low | SO pin is enabled. Output Status information transferred to Output Shift Register. |
| CSB Low–to–High | Data from the Shift Register is transferred to the Output Power Switches. |
| SO | Will change state on the rising edge of the SCLK pin signal. |
| SI | Will accept data on the falling edge of the SCLK pin signal. |

### Power Consumption

The MC33298P has extremely low power consumption in both the operating and standby modes. In the standby or "sleep" mode, with $V_{DD} \leq 2.0$ V, the current consumed by the $V_{PWR}$ pin is less than 50 μA. In the operating mode, the current drawn by the $V_{DD}$ pin is less than 4.0 mA (1.0 mA typical) while the current drawn at the $V_{PWR}$ pin is 2.0 mA maximum (1.0 mA typical). During normal operation, turning outputs "on" increases $I_{PWR}$ by only 20 μA per output. Each output experiencing a "soft short" (overcurrent conditions just under the current limit), adds 0.5 mA to the $I_{PWR}$ current.

### Paralleling of Outputs

Using MOSFETs as output switches allows the connection of any combination of outputs together. MOSFETs have an inherent positive temperature coefficient thermal feedback which modulates $R_{DS(on)}$ providing balanced current sharing between outputs without destructive operation (bipolar outputs could not be paralleled in this fashion as thermal run–away would likely occur). The device can even be operated with all outputs tied together. This mode of operation may be desirable in the event the application requires lower power dissipation or the added capability of switching higher currents. Performance of parallel operation results in a corresponding decrease in $R_{DS(on)}$ while the Output Off Open Load Detect Currents and the Output Current Limits increase correspondingly (by a factor of eight if all outputs are paralleled). Less than 56 mΩ $R_{DS(on)}$ with current limiting of 24 to 48 A will result if all outputs are paralleled together. There will be no change in the Overvoltage detect or the "Off" Output Threshold Voltage Range. The advantage of paralleling outputs within the same MC33298 affords the existence of minimal $R_{DS(on)}$ and output clamp voltage variation between outputs. Typically, the variation of $R_{DS(on)}$ between outputs of the same device is less than is 0.5%. The variation in clamp voltages (which could affect dynamic current sharing) is less than 5%. Paralleling outputs from two or more devices is possible but not recommended. This is because there is no guarantee that the $R_{DS(on)}$ and clamp voltage of the two devices will match. System level thermal design analysis and verification should be conducted whenever paralleling outputs.

## FAULT LOGIC OPERATION

### General

The MCU can perform a parity check of the fault logic operation by comparing the command 8–bit word to the status 8–bit word. Assume that after system reset, the MCU first sends an 8–bit command word, Command Word 1, to the MC33298. Each output that is to be turned "on" will have its corresponding databit low. Refer to the Data Transfer Timing diagram of Figure 16. As this word, Command Word 1, is being written into the shift register of the MC33298, a status word is being simultaneously written out and received by the MCU. However, the word being received by the MCU is the status of the previous write word to the MC33298, Status Word 0. If the command word of the MCU is written a second time (Command Word 2 = Command Word 1), the word received by the MCU, Status Word 2, is the status of Command Word 1. The timing diagram shown in Figure 16 depicts this operation. Status Word 2 is then compared with Command Word 1. The MCU will Exclusive OR Status Word 2 with Command Word 1 to determine if the two words are identical. If the two words are identical, no faults exist. The timing between the two write words must be greater than 100 μs to receive proper drain status. The system databus integrity may be tested by writing two like words to the MC33298 within a few microseconds of each other.

### Initial System Setup Timing

The MCU can monitor two kinds of faults:

(1) Communication errors on the data bus and

(2) Actual faults of the output loads.

After initial system start up or reset, the MCU will write one word to the MC33298. If the word is repeated within a few microseconds (say 5) of the first word, the word received by the MCU, at the end of the repeated word, serves as a confirmation of data bus integrity (1). At startup, the MC33298 will take 25 to 100 μs before a repeat of the first word can give the actual status of the outputs. Therefore, the first word should be repeated at least 100 μs later to verify the status of the outputs.

The SO of the MC33298 will indicate any one of four faults. The four possible faults are Over Temperature, Output Off Open Fault, Short Fault (overcurrent), and $V_{PWR}$ Overvoltage Fault. All of these faults, with the exception of the Overvoltage Fault, are output specific. Over Temperature Detect, Output Off Open Detect, and Output Short Detect are dedicated to each output separately such that the outputs are independent in operation. A $V_{PWR}$ Overvoltage Detect is of a "global" nature causing all outputs to be turned "off."

### Over Temperature Fault

Patent pending Over Temperature Detect and shutdown circuits are specifically incorporated for each individual output. The shutdown that follows an Over Temperature condition is independent of the system clock or any other logic signal. Each independent output shuts down at 155°C to 185°C. When an output shuts down due to an Over Temperature Fault, no other outputs are affected. The MCU recognizes the fault since the output was commanded to be "on" and the status word indicates that it is "off." A maximum hysteresis of 20°C ensures an adequate time delay between output turn "off" and recovery. This avoids a very rapid turn "on" and turn "off" of the device around the Over Temperature threshold. When the temperature falls below the recovery level for the Over Temperature Fault, the device will turn "on" only if the Command Word during the next write cycle indicates the output should be turned "on."

### Overvoltage Fault

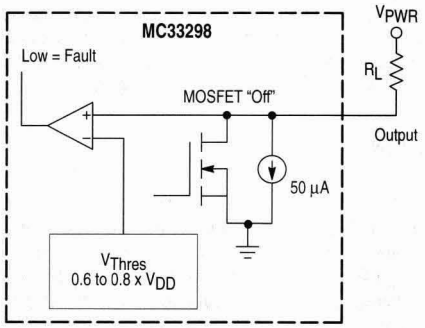
An Overvoltage condition on the $V_{PWR}$ pin will cause the MC33298 to shut down all outputs until the overvoltage condition is removed and the device is re–programmed by the SPI. The overvoltage threshold on the $V_{PWR}$ pin is specified as 28 V to 36 V with 1.0 V typical hysteresis. Following the overvoltage condition, the next write cycle sends the SO pin the hexadecimal word $FF (all ones) indicating all outputs are turned "off." In this way, potentially dangerous timing problems are avoided and the MCU reset

routine ensures an orderly startup of the loads. The MC33298 does not detect an overvoltage on the $V_{DD}$ pin. Other external circuitry, such as the Motorola MC33161 Universal Voltage Monitor, is necessary to accomplish this function.

### Output Off Open Load Fault

An Output Off Open Load Fault is the detection and reporting of an "open" load when the corresponding output is disabled (input in a logic high state). To understand the operation of the Open Load Fault detect circuit, see Figure 17. The Output Off Open Load Fault is detected by comparing the drain voltage of the specific MOSFET output to an internally generated reference. Each output has one dedicated comparator for this purpose.

**Figure 17. Output "Off" Open Load Detect**




An Output Off Open Load Fault is indicated when the output voltage is less than the Output Threshold Voltage ($V_{Thres}$) of 0.6 to 0.8 x $V_{DD}$. Since the MC33298 outputs function as switches, during normal operation, each MOSFET output should either be completely turned "on" or "off." By design the threshold voltage was selected to be between the "on" and "off" voltage of the MOSFET. During normal operation, the "on" state $V_{DS}$ voltage of the MOSFET is less than the threshold voltage and the "off" state $V_{DS}$ voltage is greater than the threshold voltage. This design approach affords using the same threshold comparator for Output Open Load Detect in the "off" state and Short Circuit Detect in the "on" state. See Figure 18 for an understanding of the Short Circuit Detect circuit. With $V_{DD}$ = 5.0 V, an "off" state output voltage of less than 3.0 V will be detected as an Output Off Open Load Fault while voltages greater than 4.0 V will not be detected as a fault.

The MC33298 has an internal pull–down current source of 50 µA, as shown in Figure 17, between the MOSFET drain and ground. This prevents the output from floating up to $V_{PWR}$ if there is an open load or internal wirebond failure. The internal comparator compares the drain voltage with a reference voltage, $V_{Thres}$ (0.6 to 0.8 x $V_{DD}$). If the output voltage is less than this reference voltage, the MC33298 will declare the condition to be an open load fault.

During steady–state operation, the minimum load resistance ($R_L$) needed to prevent false fault reporting during normal operation can be found as follows:

$$V_{PWR} = 9.0\ V\ (min)$$
$$I_{LCO} = 50\ \mu A$$
$$V_{Thres}\ (max) = (0.8 \times 5.5)V = 4.4\ V$$

Therefore, the load resistance necessary to prevent false open load fault reporting is (using Ohm's Law) equal to 92 kΩ or less.

During output switching, especially with capacitive loads, a false Output Off Open Load Fault may be triggered. To prevent this false fault from being reported an internal fault filter of 25 to 100 µs is incorporated. The duration for which a false fault may be reported is a function of the load impedance ($R_L$, $C_L$, $L_L$), $R_{DS(on)}$, and $C_{out}$ of the MOSFET as well as the supply voltage, $V_{PWR}$. The rising edge of CSB triggers a built in fault delay timer which must time out (25 to 100 µs) before the fault comparator is enabled to detect a faulted threshold. The circuit automatically returns to normal operation once the condition causing the Open Load Fault is removed.

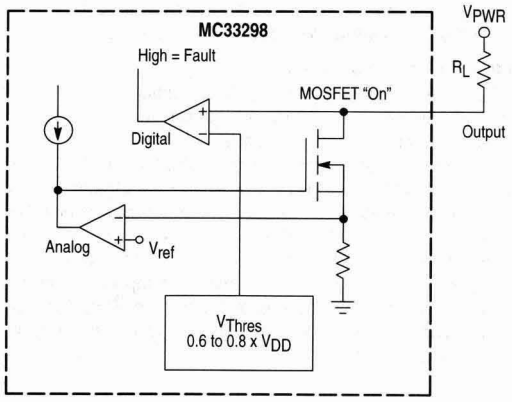
### Shorted Load Fault

A shorted load (overcurrent) fault can be caused by any output being shorted directly to supply, or an output experiencing a current greater than the current limit.

There are three safety circuits progressively in operation during load short conditions which afford system protection: 1) The device's output current is monitored in an analog fashion using a SENSEFET™ approach and limited; 2) The device's output current limit threshold is sensed by monitoring the MOSFET drain voltage; and 3) The device's output thermal limit is sensed and when attained causes only the specific faulted output to be latched "off," allowing remaining outputs to operate normally. All three protection mechanisms are incorporated in each output affording robust independent output operation.

The analog current limit circuit is always active and monitors the output drain current. An overcurrent condition causes the gate control circuitry to reduce the gate to source voltage imposed on the output MOSFET which re–establishes the load current in compliance with current limit (3.0 to 6.0 A) range. The time required for the current limit circuitry to act is less than 20 µs. Therefore, currents higher than 3.0 to 6.0 A will never be seen for more than 20 µs (a typical duration is 10 µs). If the current of an output attempts to exceed the predetermined limit of 3.0 to 6.0 A (4.0 A nominal), the $V_{DS}$ voltage will exceed the $V_{Thres}$ voltage and the overcurrent comparator will be tripped as shown in Figure 18.

**Figure 18. Short Circuit Detect and Analog Current Limiting Circuit**

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The status of SFPD will determine whether the MC33298 will shut down or continue to operate in an analog current limited mode until either the short circuit is removed or thermal shutdown is reached.

Grounding the SFPD pin will enable the short fault protection shutdown circuitry. Consider a load short (output short to supply) occurring on an output before, during, and after output turn "on." When the CSB signal rises to the high logic state, the corresponding output is turned "on" and a delay timer activated. The duration of the delay timer is 25 to 100 µs. If the short circuit takes place before the output is turned "on," the delay experienced is the entire 25 to 100 µs followed by shutdown. If the short occurs during the delay time, the shutdown still occurs after the delay time has elapsed. If the short circuit occurs after the delay time, shut– down is immediate (within 20 µs after sensing). The purpose of the delay timer is to prevent false faults from being reported when switching capacitive loads.

If the SFPD pin is at 5.0 V (or $V_{DD}$), an output will not be disabled when overcurrent is detected. The specific output will, within 5.0 to 10 µs of encountering the short circuit, go into an analog current limited mode. This feature is especially useful when switching incandescent lamp loads, where high in–rush currents experienced during startup last for 10 to 20 ms.

Each output of the MC33298 has its own overcurrent shutdown circuitry. Over temperature faults and the overvoltage faults are not affected by the SFPD pin.

Both load current sensing and output voltage sensing are incorporated for Short Fault detection with actual detection occurring slightly after the onset of current limit. The current limit circuitry incorporates a SENSEFET™ approach to measure the total drain current. This calls for the current through a small number of cells in the power MOSFET to be measured and the result multiplied by a constant to give the total current. Whereas output shutdown circuitry measures the drain to source voltage and shuts down if a threshold ($V_{Thres}$) is exceeded.

Short Fault detection is accomplished by sensing the output voltage and comparing it to $V_{Thres}$. The lowest $V_{Thres}$ requires a voltage of 0.6 times 4.5 V (the minimum $V_{DD}$ voltage) or 2.7 V to be sensed. For an enabled output, with $V_{DD} = 5.0 \pm 0.5$ V, an output voltage in excess of 4.4 V will be detected as a "short" while voltages less than 2.7 V will not be detected as "shorts."

### Over Current Recovery

If the SFPD pin is in a high logic state, the circuit returns to normal operation automatically after the short circuit is removed (unless thermal shutdown has occurred).

If the SFPD pin is grounded and overcurrent shutdown occurs; removal of the short circuit will result in the output remaining "off" until the next write cycle. If the short circuit is not removed, the output will turn "on" for the delay time (25 to 100 µs) and then turn "off" for every write cycle commanding a turn "on."

### SFPD Pin Voltage Selection

Since the voltage condition of the SFPD pin controls the activation of the short fault protection (i.e. shutdown) mode equally for all eight outputs, the load having the longest duration of in–rush current determines what voltage (state) the SFPD pin should be at. Usually if at least one load is, say an incandescent lamp, the in–rush current on that input will be milliseconds in duration. Therefore, setting SFPD at 5.0 V will prevent shutdown of the output due to the in–rush current. The system relies only on the Over Temperature Shutdown to protect the outputs and the loads. The MC33298 was designed to switch GE194 incandescent lamps with the SFPD pin in a grounded state. Considerably larger lamps can be switched with the SFPD pin held in a high logic state.

Sometimes both a delay period greater than 25 to 100 µs (current limiting of the output) followed by an immediate over current shutdown is necessary. This can be accomplished by programming the SFPD pin to 5.0 V for the extended delay period to afford the outputs to remain "on" in a current limited mode and then grounding it to accomplish the immediate shutdown after some period of time. Additional external circuitry is required to implement this type of function. An MCU parallel output port can be devoted to controlling the SFPD voltage during and after the delay period, is often a much better method. In either case, care should be taken to execute the SFPD start–up routine every time start–up or reset occurs.

### Undervoltage Shutdown

An undervoltage $V_{DD}$ condition will result in the global shutdown of all outputs. The undervoltage threshold is between 2.5 V and 4.5 V. When $V_{DD}$ goes below the threshold, all outputs are turned "off" and the SO register is reset to indicate the same.

An undervoltage condition at the $V_{PWR}$ pin will not cause output shutdown and reset. When $V_{PWR}$ is between 5.5 V and 9.0 V, the outputs will operate per the command word. However, the status as reported by the serial output (SO) pin may not be accurate. Proper operation at $V_{PWR}$ voltages below 5.5 V cannot be guaranteed.

### Deciphering Fault Type

The MC33298 SO pin can be used to understand what kind of system fault has occurred. With eight outputs having open load, over current and over temperature faults, a total of 25 different faults are possible. The SO status word received by the MCU will be compared with the word sent to the MC33298 during the previous write cycle. If the two words are not the same, then the MCU should be programmed to determine which output or outputs are indicating faults. If the command bit for any of the output switches indicating a fault is high, the fault is an open load.

The eight open load faults are therefore the ones most easily detected. Over current and over temperature faults are often related. Turning the affected output switches "off" and waiting for some time should make these faults go away. Over current and over temperature faults can not be differentiated in normal application usage.

One advantage of the synchronous serial output is that multiple faults can be detected with only one pin (SO) being used for fault status indication.

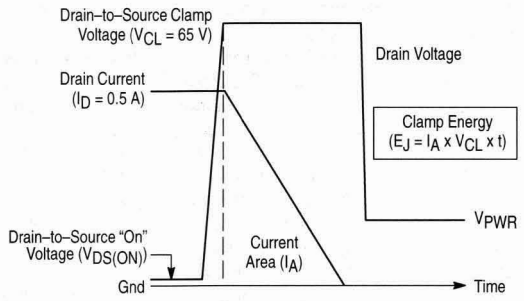
If $V_{PWR}$ experiences an overvoltage condition, all outputs will immediately be turned "off" and remain latched "off." A new command word is required to turn the outputs back "on" following an overvoltage condition.

### Output Voltage Clamping

Each output of the MC33298 incorporates an internal voltage clamp to provide fast turn–off and transient protection of the output. Each clamp independently limits the drain to source voltage to 65 V at drain currents of 0.5 A and keeps the output transistors from avalanching by causing the transient energy to be dissipated in the linear mode (see Figure 19). The total energy ($E_J$) can be calculated by multiplying the current area under the current curve ($I_A$) during the time the clamp is active and the clamp voltage ($V_{CL}$).

Characterization of the output clamps, using a single pulse repetitive method at 0.5 A, indicate the maximum energy to be 100 mJ at 25°C and 25 mJ at 125°C per output. Using a single pulse non–repetitive method at 0.5 A the clamps are capable of 2.0 Joules at 25°C and 0.5 Joules at 125°C.

**Figure 19. Output Voltage Clamping**




## THERMAL CHARACTERIZATION

### Thermal Model

Logic functions take up a very small area of the die and generate negligible power. In contrast, the output transistors take up most of the die area and are the primary contributors of power generation. The thermal model shown in Figure 20 was developed for the MC33298 mounted on a typical PC board. The model is accurate for both steady state and transient thermal conditions. The components $R_{d0}$, $R_{d1}$, $R_{d2}$, ..., and $R_{d7}$ represent the steady state thermal resistance of the silicon die for transistor outputs 0, 1, 2, ..., and 7, while $C_{d0}$, $C_{d1}$, $C_{d2}$, ..., and $C_{d7}$ represent the corresponding thermal capacitance of the silicon die transistor outputs and plastic. The device area and die thickness determine the values of these specific components.

The thermal impedance of the package from the internal mounting flag to the outside environment is represented by the terms $R_{pkg}$ and $C_{pkg}$. The steady state thermal resistance of leads and the PC board make up the steady state package thermal resistance, $R_{pkg}$. The thermal capacitance of the package is made up of the combined capacitance of the flag and the PC board. The mold compound was not modeled as a specific component but is factored into the other overall component values.

The battery voltage in the thermal model represents the ambient temperature the device and PC board are subjected to. The $I_{PWR}$ current source represents the total power dissipation and is calculated by adding up the power dissipation of each individual output transistor. This is easily done by knowing $R_{DS(on)}$ and load current of the individual outputs.

Very satisfactory steady state and transient results have been experienced with this thermal model. Tests indicate the model accuracy to have less than 10% error. Output interaction with an adjacent output is thought to be the main contributor to the thermal inaccuracy. Tests indicate little or no detectable thermal affects caused by distant output transistors which are isolated by one or more other outputs. Tests were conducted with the device mounted on a typical PC board placed horizontally in a 33 cubic inch still air enclosure. The PC board was made of FR4 material measuring 2.5″ by 2.5″, having double–sided circuit traces of 1.0 oz. copper soldered to each device pin. The board temperature was measured with thermal couple soldered to the board surface one inch away from the center of the device. The ambient temperature of the enclosure was measured with a second thermal couple located over the center and one inch distant from device.

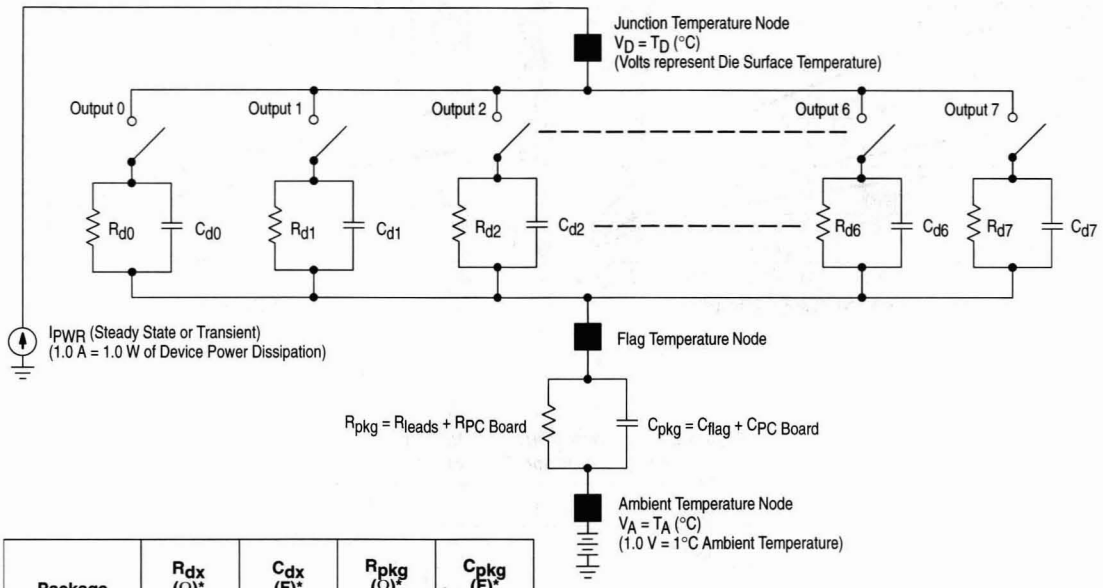
### Thermal Performance

Figure 20 shows the worst case thermal component parameters values for the MC33298 in the 20 pin plastic power DIP and the SOP–24 wide body surface mount package. The power DIP package has Pins 5, 6, 15, and 16 connected directly to the lead frame flag. The parameter values indicated take into account adjacent output cell thermal pulling effects as well as different output combinations. The characterization was conducted over power dissipation levels of 0.7 to 17 W. The junction–to–ambient temperature thermal resistance was found to be 37°C/W with a single output active (31°C/W with all outputs dissipating equal power) and in conjunction with this, the thermal resistance from junction to PC board ($R_{junction–board}$) was found to be 27°C/W (board temperature, measured 1″ from device center). In addition, the thermal resistance from junction–to–heatsink lead was found to approximate 10°C/W. Devoting additional PC board metal around the heatsinking pins improved $R_{pkg}$ from 30° to 28°C/W.

The SOP–24 package has Pins 5, 6, 7, 8, 17, 18, 19, and 20 of the package connected directly to the lead frame flag. Characterization was conducted in the same manner as for the DIP package. The junction–to–ambient temperature resistance was found to be 40°C/W with a single output active (34°C/W with all outputs dissipating equal power) and the thermal resistance from junction–to–PC board ($R_{junction–board}$) to be 30°C/W (board temperature, measured 1″ from device center). The junction–to–heatsink lead resistance was found again to approximate 10°C/W. Devoting additional PC board metal around the heatsinking pins for this package improved the $R_{pkg}$ from 33° to 31°C/W.

The total power dissipation available is dependent on the number of outputs enabled at any one time. At 25°C the $R_{DS(on)}$ is 450 mΩ with a coefficient of 6500 ppm/°C. For the junction temperature to remain below 150°C, the maximum available power dissipation must decrease as the ambient temperature increases. Figures 21 and 22 depict the per output limit of current at ambient temperatures necessary for the plastic DIP and SOP packages respectively when one, four, or eight outputs are enabled "on." Figure 23 depicts how the $R_{DS(on)}$ output value is affected by junction temperature.

**Figure 20. Thermal Model (Electrical Equivalent)**




| Package | $R_{dx}$ (Ω)* | $C_{dx}$ (F)* | $R_{pkg}$ (Ω)* | $C_{pkg}$ (F)* |
|---|---|---|---|---|
| 20 Pin DIP | 7.0 | 0.002 | 30 | 0.2 |
| SOP–24L | 7.0 | 0.002 | 33 | 0.15 |

* Ω = °C/W, F = W s/°C, $I_{PWR}$ = W, and $V_A$ = °C

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**Figure 21. Maximum DIP Package Steady State Output Current versus Ambient Temperature**

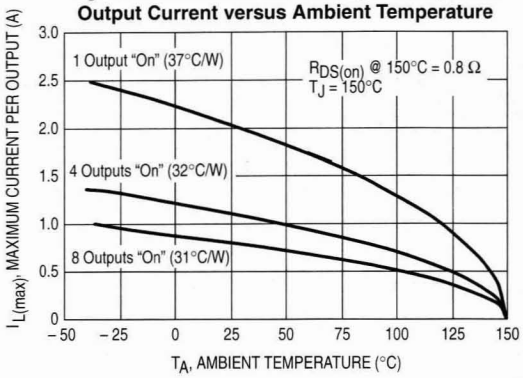



**Figure 22. Maximum SOP Package Steady State Ouput Current versus Ambient Temperature**

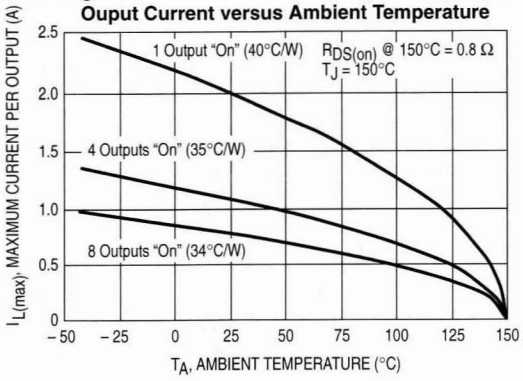
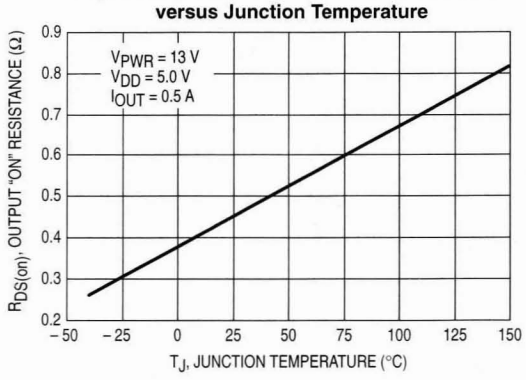



**Figure 23. Maximum Output "On" Resistance versus Junction Temperature**

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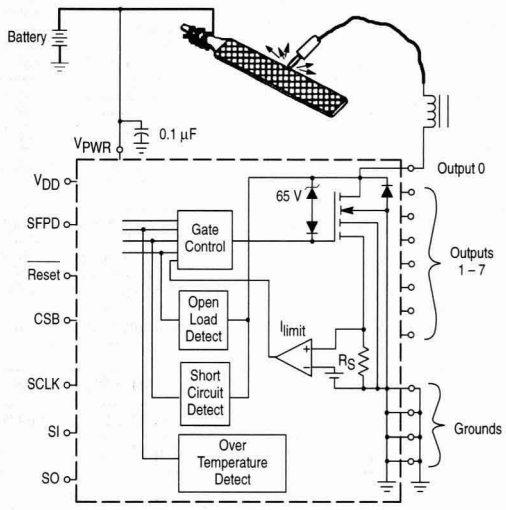
### Latch–Up Immunity

Device latch–up caused by substrate injection has been characterized. Latch–up immunity has both a dc and a transient immunity component. DC latch–up immunity results indicate the device to be capable of withstanding in excess of four amps of reverse current out of any of the output transistors while the control logic continues to function normally. The logic control current ($I_{DD}$) was found to increase by only 0.6 mA with four amps of current being pulled out of an output. Additionally, the $I_{PWR}$ current was found to increase by only 0.15 mA under the same condition. These increases are a result of minority carriers being injected into substrate and subsequently being collected.

The following procedure has been developed to test for transient latch–up immunity and has been applied to this automotive circuit design. Results of transient testing indicate the device to operate properly at output currents greater than 1.5 A. The procedure tests for the device's immunity to intermittent load to battery current connection with the device controlling an inductive load. Appropriately termed "the file test," the battery is connected to a shop file while the lead to the inductive load is dragged across the files surface causing intermittent load opens producing lots of arcs, sparks, and smoke, plus severe transients (see Figure 24). It is during these severe transients that latch–up most likely could occur. The battery voltage used for this test was 18 V and the inductive load was 2.0 mH. These values were found to produce severe transient stresses of the device outputs. All outputs must maintain operation and input control during transient generation to pass "the file test."

The device's input control currents were found to remain stable and were not affected by dc or transient latch–up immunity testing.

**Figure 24. Transient Latch–Up Immunity File Test**




## APPLICATIONS INFORMATION

### SIOP Communication

Two common communication protocols used in Motorola's microprocessors are the Serial Peripheral Interface (SPI) and Synchronous Input Output Port (SIOP). SIOP is a subset of the more flexible SPI and the simpler of the two protocols. SIOP is used on many of the MC68HC05 family of microcontrollers. Restrictions of the SIOP protocol include: 1) the SCLK frequency is fixed at one–fourth the internal clock rate and 2) the polarity of the SCLK signal is fixed.

By way of example, the MC68HC05P9 utilizes SIOP protocol and is not directly compatible with the serial input requirements of the MC33298. Specifically, the MC33298 accepts data on the falling edge of SCLK whereas its rising edge triggers data transfer in the SIOP protocol. SCLK is high during SIOP transmissions, which is the opposite of what the MC33298 requires.

Though designed specifically for SPI communication protocol, the MC33298 can easily be adapted to communicate with SIOP protocol through the use of software. The amount of code required to implement SPI in software is relatively small, so the only major drawback is a slower transfer of data. The software routine shown in Table 1 completes a transfer in about 100 µs.

### Cost

The bottom line relates to cost. The MC33298 is a very cost effective octal output serial switch for applications typically encountered in the automotive and industrial market segments. To accomplish only the most basic serial switch function the MC33298 offers, using a discrete semiconductor approach, would require the use of at least eight logic level power MOSFETs for the outputs and two shift registers for the I/O plus other miscellaneous "glue" components. Additional circuitry would have to be incorporated to accomplish the protection features offered by the MC33298. Other noteworthy advantages the MC33298 offers are conservation of power and board space, requirement of fewer application components, and enhanced application reliability. The MC33298 is available at a fraction of the cost required for discrete component implementation and represents true value.

The MC33298 represents a cost effective device having advanced performance and features and worthy of consideration.

**Table 1. Program to Exercise the MC33298 Using SPI (Having Only SIOP) Protocol**

**SET LABELS FOR OUTPUT REGISTERS**

| | | | |
|---|---|---|---|
| PORTA | EQU | $0000 | ;SPI Port<br>;DO (Data Out), SCLK, CS, RESET, X, FLTOUT, DI (Data In) |
| PORTB | EQU | $0001 | ;Normally the SIOP Port. SIOP will be disabled |
| PORTC | EQU | $0002 | ;A–D Converter Port |
| PORTD | EQU | $0003 | ;Timer Capture Port |
| DDRA | EQU | $0004 | ;Data Direction Register for SPI Port |
| DDRB | EQU | $0005 | ;Data Direction Register for SCLK, SDI, SDO, 11111 |
| DDRC | EQU | $0006 | ;Data Direction Register for A–D Converter Port |
| DDRD | EQU | $0007 | ;Data Direction Register for PORTD, Timer Capture |

| | | | |
|---|---|---|---|
| DTOUT | EQU | $0080 | ;Register for the SPI output data. This register will be used for a Serial–to–Parallel transformation. |
| DATAIN | EQU | $0081 | ;Input Register for SPI. Also used for a Serial–to–Parallel transformation. |
| VALUE | EQU | $0082 | ;Register to store the SPI. Also used for a Serial–to–Parallel transformation. |
| DATA1 | EQU | $0083 | ;Miscellaneous data register |

| | | | |
|---|---|---|---|
| SCR | EQU | $000A | ;Label for SIOP control register, 0 SPE 0 MSTR 0 0 0 0. |
| SSR | EQU | $000B | ;Label for SIOP status register, SPIF DCOL 0 0 0 0 0 0, Read Only Register. |
| SDR | EQU | $000C | ;Label for SIOP data register. |

| | | | |
|---|---|---|---|
| | ORG | $0100 | ;Program starts at first byte of User ROM. |
| INIT | RSP | | ;Reset Stack Pointer to $FF. |

**INITIALIZE THE DATA REGISTERS AND THEIR DATA DIRECTION BIT REGISTERS**

| | | | |
|---|---|---|---|
| | LDA | #$FE | ;Configuration PortA as the SPI Port. |
| | STA | DDRA | ;All but Bit 0 will be outputs. |

| | | | |
|---|---|---|---|
| | LDA | #$FF | |
| | STA | DDRB | ;Configure Register B as an output. SIOP is not used for the MC33298, but is available for another peripheral. |
| | STA | DDRC | ;Configure Register C as an output |
| | STA | DDRD | ;Configure Register D as an output |

| | | | |
|---|---|---|---|
| | LDA | #%00010000 | ;Initialize the SIOP Control Register. |
| | STA | SCR | ;Disable SIOP by clearing Bit 6. |

**SELECT THE DESIRED OUTPUTS**

| | | | |
|---|---|---|---|
| TOP | LDA<br>STA | #$55<br>VALUE | Select outputs of MC33298 to be turned "on." This instruction is left inside the loop to include changes while running the program. A set bit will cause the associated MC33298 output to be "off." The value register is uncorrupted by the serial–to–parallel conversion. |
| | BSET | 4,PORTA | ;Reset the MC33298. |
| | BCLR | 4,PORTA | ;Also establishes a + or – trigger source |
| | BSET | 4,PORTA | ;The MC33298 is reset with a logic low. |

| | | | |
|---|---|---|---|
| | BCLR | 5,PORTA | ;Enable MC33298 by pulling CSB (chip select bar) low. Within the MC33298 the Fault Status is transferred to the MC33298 Serial Register at a falling edge of CSB. |

| | | | |
|---|---|---|---|
| | LDA | VALUE | ;Select outputs to be turned "on." |
| | STA | DTOUT | ;Save Output Word (Value) to check for fault. |

10

**SPI TRANSFER LOOP**

| | | | |
|---|---|---|---|
| | LDX | #$07 | ;Set the number of Read/Shift cycles. |

| | | | |
|---|---|---|---|
| LOOP | ASL | DATAIN | ;Shift a Zero into LSB of DATAIN and ASL other bits. |
| | ASL | DTOUT | ;Test value currently in MSB of DTOUT. |
| | BCS | DOONE | ; |
| | BCLR | 7,PORTA | ;MSB was Zero, so clear DATA OUT bit. |
| | JMP | GOON | |
| DOONE | BSET | 7,PORTA | ;MSB was One, so set the DATA OUT bit. |
| GOON | BSET | 6,PORTA | ;Set the SCLK. Serial Output pin of the MC33298 changes state on the rising edge of the SCLK. Read the next bit coming from the MC33298. |

| | | | |
|---|---|---|---|
| | BRCLR | 0,PORTA, WZZER0 | ;Read the bit and branch if Zero. LSB of DATAIN is already cleared due to the ASL above. |
| | BSET | 0,DATAIN | ;Bit was One. Set the next bit in DATAIN. |

| | | | |
|---|---|---|---|
| WZZER0 | BCLR | 6,PORTA | ;Clear SCLK. Falling edge causes the MC33298 to read the next bit from the MCU. |
| | DECX | | |
| | BPL | LOOP | ;Continue to loop eight times until the SPI transfer is complete. |

| | | | |
|---|---|---|---|
| | BSET | 5,PORTA | ;Transfer control signal to output transistors. |

**ESTABLISH A BRIEF DELAY**

| | | | |
|---|---|---|---|
| | LDA | #16 | |
| PAUSE | DECA | | ;3 Clock cycles |
| | BNE | PAUSE | ;3 Clock cycles |
| | BCLR | 5,PORTA | ;Transfer output status to Serial Register. |
| | JSR | FLTCHK | ;Jump to Fault Check subroutine. |

| | | | |
|---|---|---|---|
| | JSR | DLY | ;Delay 1/T msec |

| | | | |
|---|---|---|---|
| | BSET | 5,PORTA | ;Deselect the MC33298. |
| | BRA | TOP | ;Return to top of loop. |

**SUBROUTINE TO CHECK FOR FAULTS**

| | | | |
|---|---|---|---|
| FLTCHK | BCLR | 1,PORTA | ;CLR the Fault pin. |
| | LDA | DATAIN | |
| | CMP | VALUE | ;Check for Faults. |
| | BEQ | NOFLT | ;If there is no Fault, continue. |
| | BSET | 1,PORTA | ;Activate Fault LED. |
| NOFLT | RTS | | |

**DELAY SUBROUTINE**

| | | | |
|---|---|---|---|
| DLY | STA | DATA1 | ;Save Accumulator in RAM. |
| | LDA | #$04 | ;Do outer loop 4 times, roughly 4.0 ms. |
| OUTLP | CLRX | | ;X used as Inner Loop Count |
| INNRLP | DECX | | ;0–FF, FF–FE, … 1–0 256 loops. |
| | BNE | INNRLP | ;6CYC* 256* 1.0 µs/CYC = 1.53 ms |
| | DECA | | ;4–3. 3–2, 2–1, 1–0 |
| | BNE | OUTLP | ;1545CYC* 4*1.0 µs/CYC = 6.18 ms |
| | LDA | DATA1 | ;Recover Accumulator value. |
| | RTS | | ;Return from subroutine. |

| | | | |
|---|---|---|---|
| | ORG | $1FF | |
| | FDB | INIT | |

MOTOROLA

# MC79076
# MCCF79076

*Product Preview*

## Electronic Ignition Control Circuit

The MCCF79076, in conjunction with an appropriate Motorola Power Darlington Transistor, provides an economical solution for automotive ignition applications. The MCCF79076 offers optimum performance by providing closed loop operation of the Power Darlington in controlling the ignition coil current.

The MCCF79076 incorporates Flip–Chip Technology which involves the formation of solder bumps, rather than traditional wire bonds, to establish mechanical and electrical contact to the semiconductor chip. This process affords a unique device having improved reliability at elevated operating temperatures.

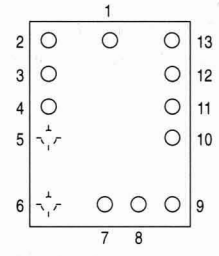
- Solder Bumped for Flip–Chip Assembly
- Ignition Coil Voltage Internally Limited to 375 V
- Coil Current Limiting to 7.5 A
- Output On–Time (Dwell) Control
- Dwell Feedback Control to Sense Coil Variation
- Hall Sensor Input
- $-30°C \le T_A \le +140°C$ Ambient Operating Temperature

**ELECTRONIC IGNITION CONTROL CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

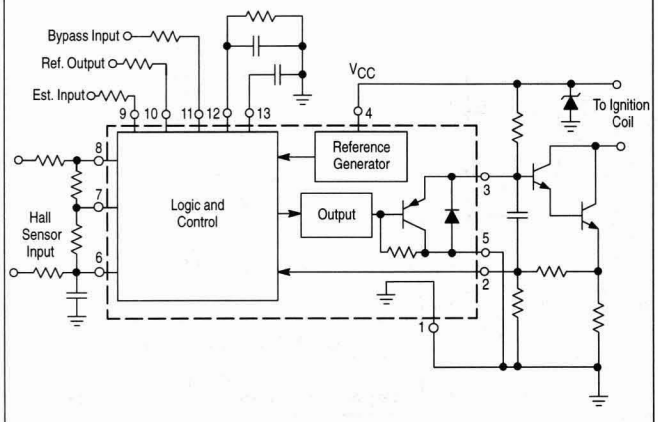
**DW SUFFIX**
PLASTIC PACKAGE
CASE 751G
(SO–16L)

**FLIP–CHIP CONFIGURATION**




Top View
(Bump Side)

**Simplified Block Diagram and Application Circuit**




**BUMP CONNECTIONS**

1. High Ground
2. Output Current Limit
3. Dwell Output
4. Supply
5. Low Ground
6. Reference Dwell Input
7. Advance Input
8. Bias Voltage
9. Est Input
10. Reference Output
11. Bypass Input
12. 900 RPM Detector
13. Dwell Control

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MCCF79076 | $T_A = -30°$ to $+125°C$ | Flip–Chip |
| MC79076DW | | SO–16L |

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MOTOROLA

# MCCF33093

*Product Preview*

## Ignition Control Flip-Chip

Designed for automotive ignition applications. The MCCF33093 provides outstanding control of the ignition coil when used with an appropriate Motorola Power Darlington Transistor. Engine control systems utilizing the MCCF33093 exhibit exceptional fuel efficiency and low exhaust emissions. The MCCF33093 requires a differential Hall Sensor input for proper operation.

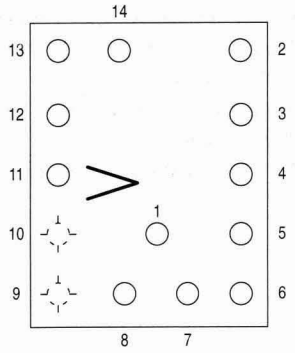
The MCCF33093 utilizes Flip-Chip Technology in which solder bumps, rather than traditional wire bonds, are created to establish mechanical and electrical contact to the chip. This process affords a unique device having improved reliability at elevated operating temperatures.

- Solder Bumped for Flip-Chip Assembly
- External Capacitors to Set Device Timing
- Overvoltage Shutdown Protection
- Auto Start-Up Capability Once Overvoltage Condition Ceases
- Allows for Push Start-Up in Automotive Applications
- Ignition Coil Current Limiting
- Ignition Coil Voltage Limiting
- Bandgap Reference for Enhanced Stability Over Temperature
- Negative Edge Filter for Hall Sensor Input Transient Protection
- Hall Sensor Inputs for RPM and Position Sensing
- $-30°C \le T_A \le +140°C$ Ambient Operating Temperature

**IGNITION CONTROL FLIP–CHIP**

**SEMICONDUCTOR TECHNICAL DATA**

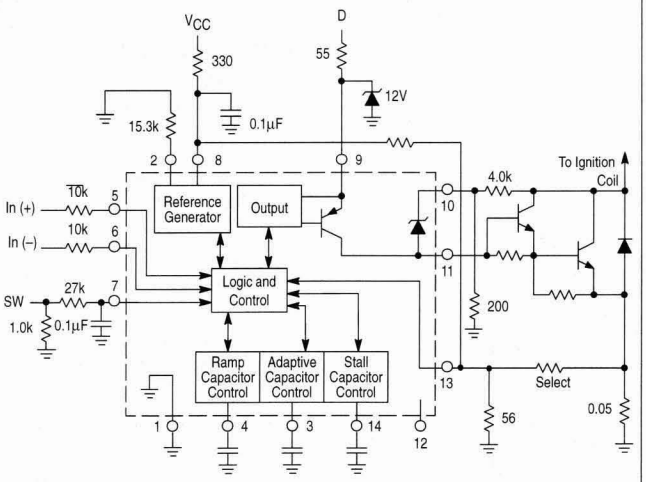
**FLIP-CHIP CONFIGURATION**




(Backside View)

0.116 inch x 0.091 inch
Backside orientation marking
indicated by arrow oriented as shown

**Simplified Block Diagram and Application Circuit**




**BUMP CONNECTIONS**

1. Ground
2. Master Bias
3. Adaptive Capacitor
4. Ramp Capacitor
5. Positive Hall Input
6. Negative Hall Input
7. Start
8. Supply
9. Distributor Signal
10. Coil
11. Output
12. Process Test
13. Emitter of Darlington
14. Stall Capacitor

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MCCF33093 | $T_A$ = –30° to +140°C | Flip–Chip |

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MOTOROLA

# MCCF33094

*Product Preview*

## Ignition Control Flip-Chip

Designed for automotive ignition applications. The MCCF33094 provides outstanding control of the ignition coil when used with an appropriate Motorola Power Darlington Transistor. Engine control systems utilizing the MCCF33094 exhibit exceptional fuel efficiency and low exhaust emissions. For proper operation, the MCCF33094 requires a single Hall Sensor input signal, which is compared to an accurate internal reference.

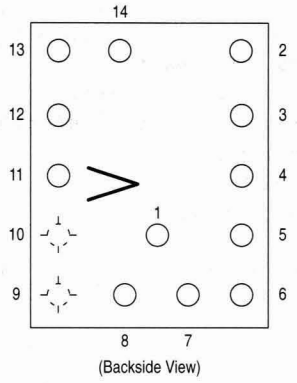
The MCCF33094 utilizes Flip-Chip Technology in which solder bumps, rather than traditional wire bonds, are created to establish mechanical and electrical contact to the chip. This process affords a unique device having improved reliability at elevated operating temperatures.

- Solder Bumped for Flip-Chip Assembly
- External Capacitors to Set Device Timing
- Overvoltage Shutdown Protection
- Auto Start-Up Capability Once Overvoltage Condition Ceases
- Allows for Push Start-Up in Automotive Applications
- Ignition Coil Current Limiting
- Ignition Coil Voltage Limiting
- Bandgap Reference for Enhanced Stability Over Temperature
- Negative Edge Filter for Hall Sensor Input Transient Protection
- Hall Sensor Inputs for RPM and Position Sensing
- $-30°C \le T_A \le +140°C$ Ambient Operating Temperature

**IGNITION CONTROL FLIP–CHIP**

**SEMICONDUCTOR TECHNICAL DATA**

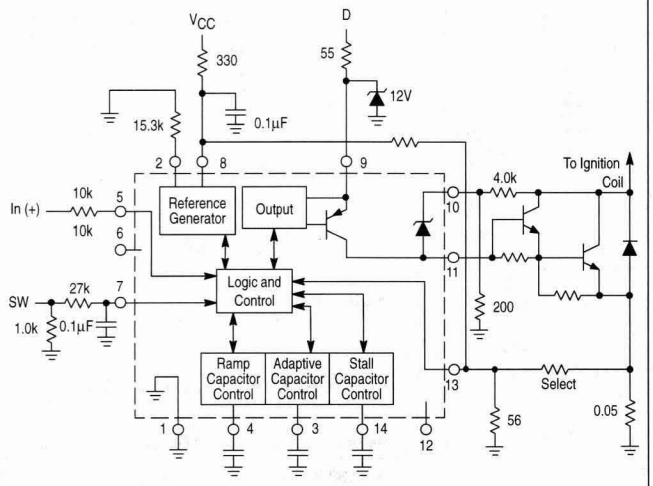
**FLIP-CHIP CONFIGURATION**




(Backside View)

0.116 inch x 0.091 inch
Backside orientation marking
indicated by arrow oriented as shown

**Simplified Block Diagram and Application Circuit**




**BUMP CONNECTIONS**

1. Ground
2. Master Bias
3. Adaptive Capacitor
4. Ramp Capacitor
5. Positive Hall Input
6. N.C.
7. Start
8. Supply
9. Distributor Signal
10. Coil
11. Output
12. Process Test
13. Emitter of Darlington
14. Stall Capacitor

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MCCF33094 | $T_A$ = –30° to +140°C | Flip–Chip |

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MOTOROLA

*Advance Information*

# Integral Alternator Regulator

**MCCF33095**
**MC33095**

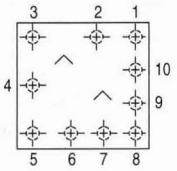
**INTEGRAL ALTERNATOR REGULATOR**

**SEMICONDUCTOR TECHNICAL DATA**

The MCCF33095 (Flip–Chip) and MC33095 (Surface Mount) are regulator control integrated circuits designed for use in automotive 12 V alternator charging systems. Few external components are required for full system implementation. These devices provide control for a broad range of 12 V alternator charging systems when used in conjunction with the appropriate Motorola Power Darlington transistor to control the field current of the specific alternator.

Both versions have internal detection and protection features to withstand extreme electrical variations encountered in harsh automotive environments. Flip–Chip Technology allows the MCCF33095 to operate at higher ambient temperatures than the surface mount version in addition to withstanding severe vibration and thermal shock with a high degree of reliability.

- Constant Frequency with Variable Duty Cycle Operation
- Adjusts System Charging to Compensate for Changes in Ambient Temperature
- Slew Rate Control to Reduce EMI
- Lamp Pin to Indicate Abnormal Operating Conditions
- Shorted Field Protection
- Resumes Normal Operation Once Fault Condition Ceases
- Operation from –40°C to 170°C for Flip–Chip and –40°C to 125°C for SO–14
- Surface Mount or Solder Bump Processed Flip–Chip Assembly Versions



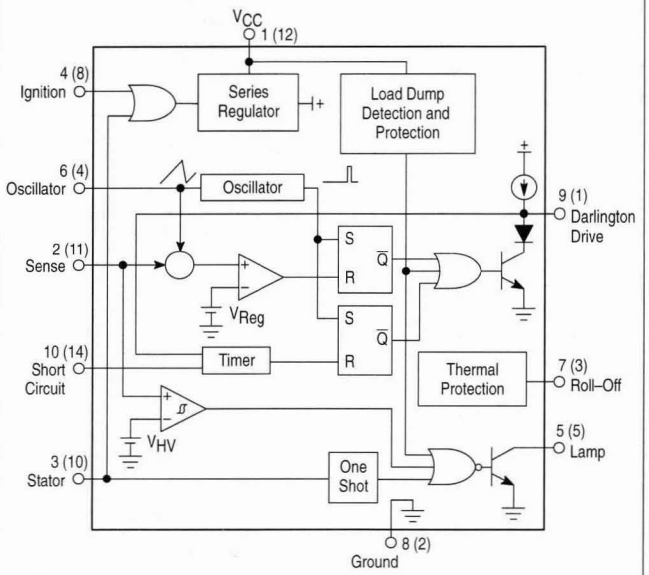

**FLIP–CHIP CONFIGURATION**
(Backside View)
Back marking is oriented as shown

**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

| Bump | Function | SO–14 (Note 1) |
|---|---|---|
| 1 | $V_{CC}$ | (12) |
| 2 | Sense | (11) |
| 3 | Stator | (10) |
| 4 | Ignition | (8) |
| 5 | Lamp | (5) |
| 6 | Oscillator | (4) |
| 7 | Roll–Off | (3)(Note 2) |
| 8 | Ground | (2) |
| 9 | Darlington Drive | (1) |
| 10 | Short Circuit | (14) |

**NOTES:** 1. No connections to Pins 3, 6, 7, 9 and 13.
2. Connected to ground internal to package.

**Simplified Block Diagram**




This device contains 145 active transistors.

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MCCF33095 | $T_A$ = –40° to +170°C | Flip–Chip |
| MC33095D | $T_A$ = –40° to +125°C | SO–14 |

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**MAXIMUM RATINGS** (Notes 1 and 3)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Steady State $V_{CC}$, $V_{IGN}$, $V_{STA}$ | – | 9.0 to 24 | V |
| $V_{CC}$ and $V_{IGN}$ Transient | – | 80 | V |
| Bump Shear Strength (Flip–Chip) | – | 8.0 | Grams/Bump |
| Thermal Characteristics (Thermal Resistance)<br>Junction–to–Substrate (Flip–Chip)<br>Junction–to–Ambient (SO–14) | <br>$R_{\theta JS}$<br>$R_{\theta JA}$ | <br>29<br>145 | °C/W |
| Junction Temperature<br>Flip–Chip<br>SO–14 | $T_J$ | <br>170<br>150 | °C |
| Operating Ambient Temperature Range<br>Flip–Chip<br>SO–14 | $T_A$ | <br>–40 to +170<br>–40 to +125 | °C |

**ELECTRICAL CHARACTERISTICS** (Limit values are given for $-40°C \le T_A \le 150°C$ (Flip–Chip), $-40°C \le T_A \le 125°C$ (SO–14) and typical values represent approximate mean value at $T_A = 25°C$. Oscillator, Roll–Off, Ground, Short Circuit = 0 V, and 12 V ≤ $V_{CC}$, Sense, Stator, Ignition ≤ 16 V, unless otherwise specified.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **SUPPLY** ($V_{CC}$) | | | | | |
| Supply Current<br>Disabled (Ignition = 0.5 V, Stator = 5.0 V)<br>Enabled ($V_{CC}$, Sense = 17 V, Ignition = 1.4 V) | $I_{CC}$ | <br>–50<br>0 | <br>0.2<br>3.9 | <br>300<br>25 | <br>µA<br>mA |
| Darlington Drive Overvoltage<br>Disable Threshold ($V_{CC}$, Ignition, Short Circuit = 19 V to 29 V Ramp, Stator = 10 V)<br>Hysteresis ($V_{CC}$, Stator, Ignition, Short Circuit = 29 V to 19 V Ramp) | <br>$V_{CODD}$<br>$V_{CODDH}$ | <br>19<br>– | <br>26<br>4.2 | <br>28.5<br>– | V |
| Lamp Overvoltage<br>Disable Threshold ($V_{CC}$, Stator, Ignition, Short Circuit = 19 V to 29 V Ramp)<br>Hysteresis | <br>$V_{COL}$<br>$V_{COLH}$ | <br>19<br>– | <br>22.3<br>0.3 | <br>29.5<br>– | V |
| **SENSE** | | | | | |
| Sense Current (Oscillator = 2.0 V) | $I_{SNS}$ | –10 | 0.6 | 10 | µA |
| Calibration Voltage (50% Duty Cycle) (Note 5) | $V_R$ | 12.25 | 14.6 | 17.5 | V |
| Lamp Comparator Detect Threshold | $V_{SCD}$ | – | 16.3 | – | V |
| Proportional Control Range | $M_V$ | 50 | 187.4 | 350 | mV |
| Lamp Comparator Reset Threshold | $V_{HV}$ | 15.4 | 15.9 | 16.4 | V |
| Lamp Hysteresis | $V_{HYS}$ | 20 | 416.6 | 600 | mV |
| **STATOR** | | | | | |
| Propagation Delay (Lamp–to–High, Stator = 15 V to 6.0 V) | $t_{STA}$ | 6.0 | 59.4 | 600 | ms |
| Reset Threshold Voltage (Lamp–to–Low, Stator = 5.0 V to 11 V) | $V_{IH}$ | 6.0 | 8.8 | 11 | V |
| Input Current (Sense = 18 V, Oscillator = 2.0 V) | $I_{STA}$ | –10 | 1.5 | 10 | µA |
| **LAMP** | | | | | |
| Saturation Voltage (Lamp = 14 mA) | $V_{OLL}$ | 0 | 111.8 | 350 | mV |
| Leakage Current (Sense = 1.0 V, Lamp = 2.5 V) | $I_{OHL}$ | –50 | 0.8 | 50 | µA |
| Saturation Voltage ($V_{CC}$, Sense, Stator, Ignition = 30 V, Lamp = 20 mA) | $V_{OOLL}$ | 0 | 147.4 | 350 | mV |

**NOTES:** 1. $V_{CC}$ applied through a 250 Ω resistor.
2. Sense input applied through a 100 kΩ and 50 kΩ resistor divider to generate one–third $V_{bat}$.
3. Stator and Ignition inputs applied through a 20 kΩ resistor.
4. Short Circuit input applied through a 30 kΩ resistor.
5. Oscillator pin connected in series with 0.022 µF capacitor to ground.

**ELECTRICAL CHARACTERISTICS (continued)** (Limit values are given for $-40°C \le T_A \le 150°C$ (Flip–Chip), $-40°C \le T_A \le 125°C$ (SO–14) and typical values represent approximate mean value at $T_A = 25°C$. Oscillator, Roll–Off, Ground, Short Circuit = 0 V, and $12\ V \le V_{CC}$, Sense, Stator, Ignition $\le 16$ V, unless otherwise specified.)

**DARLINGTON DRIVE**

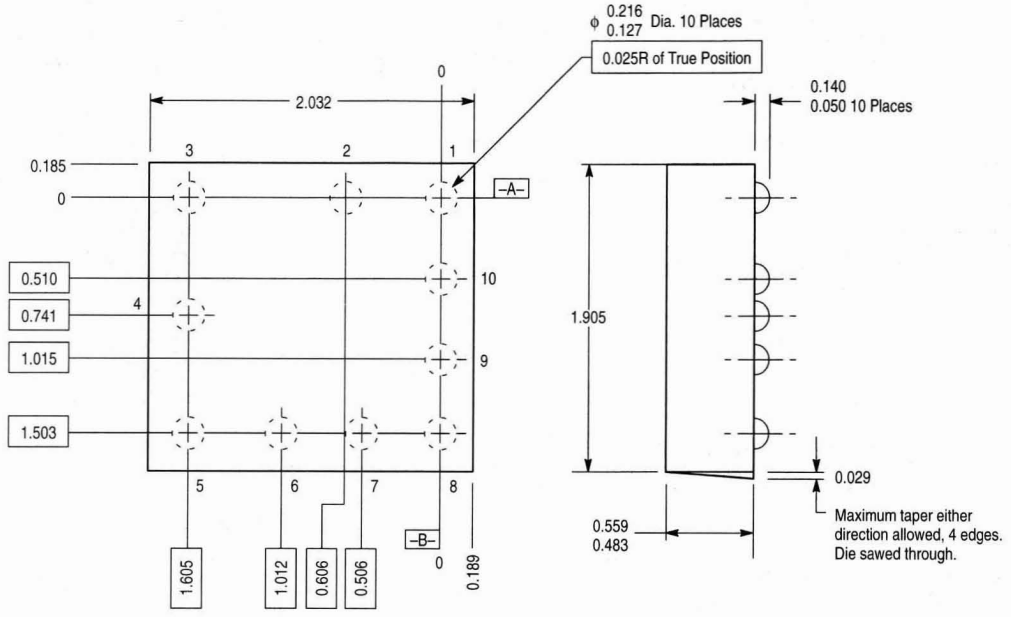
| | | | | | |
|---|---|---|---|---|---|
| Source Current (Pins $V_{CC}$, Sense, Ignition = 9.0 V, Darlington Drive = V across Power Darlington) | $I_{OHDD}$ | 4.0 | 7.6 | 20 | mA |
| Saturation Voltage (Sense = 18 V, Oscillator = 2.0 V, Darlington Drive = –100 μA) | $V_{OLDD}$ | 0 | 300.1 | 350 | mV |
| Minimum "On" Time (Sense = 18 V) (Note 5) | $t_{DD}$ | 200 | 697.8 | 700 | μs |
| Frequency (Note 5) | $F_{OSC}$ | 75 | 174.7 | 325 | Hz |
| Minimum Duty Cycle (Sense = 18 V) (Note 5) | $DC_{DD}$ | 4.0 | 12.2 | 13 | % |
| Rise Time (10% to 90%) (Note 5) | $t_r$ | 10 | 21.4 | 50 | μs |
| Fall Time (90% to 10%) (Note 5) | $t_f$ | 10 | 23.7 | 50 | μs |

**SHORT CIRCUIT**

| | | | | | |
|---|---|---|---|---|---|
| Duty Cycle (Note 5) | $DC_{SC}$ | 1.0 | 1.7 | 5.0 | % |
| "On" Time (Short Circuit High, Short Circuit = 8.0 V) (Note 5) | $PW_{SC}$ | 60 | 99 | 660 | μs |

**NOTES:** 1. $V_{CC}$ applied through a 250 Ω resistor.
2. Sense input applied through a 100 kΩ and 50 kΩ resistor divider to generate one–third $V_{bat}$.
3. Stator and Ignition inputs applied through a 20 kΩ resistor.
4. Short Circuit input applied through a 30 kΩ resistor.
5. Oscillator pin connected in series with 0.022 μF capacitor to ground.

**Figure 1. Flip–Chip Mechanical Dimensions**




**NOTES:** 1. All dimensions shown indicated in millimeters.
2. [ ] Denotes basic dimension having zero tolerance and describes the theoretical exact location (true position) or contour.

10

**Figure 2. Pins 1, 3 and 4 Field Transient Decay**

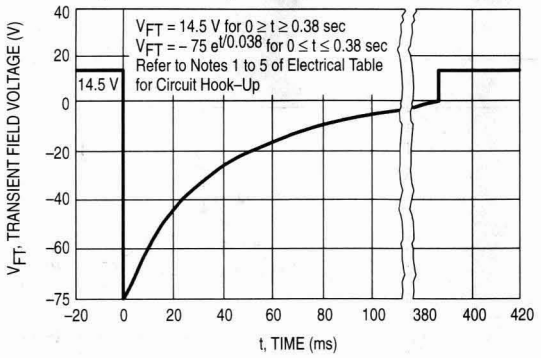

$V_{FT}$ = 14.5 V for 0 ≥ t ≥ 0.38 sec
$V_{FT}$ = – 75 $e^{t/0.038}$ for 0 ≤ t ≤ 0.38 sec
Refer to Notes 1 to 5 of Electrical Table for Circuit Hook–Up
14.5 V
$V_{FT}$, TRANSIENT FIELD VOLTAGE (V)
t, TIME (ms)

**Figure 3. Pins 1 and 4 Load Dump Transient Decay**

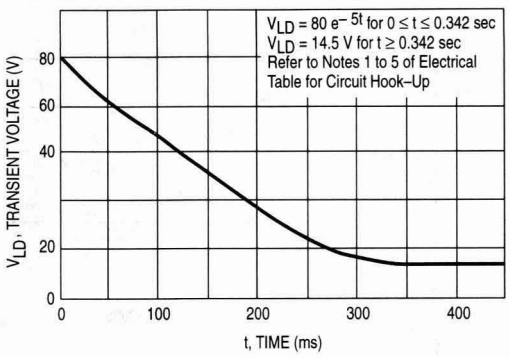

$V_{LD}$ = 80 $e^{-5t}$ for 0 ≤ t ≤ 0.342 sec
$V_{LD}$ = 14.5 V for t ≥ 0.342 sec
Refer to Notes 1 to 5 of Electrical Table for Circuit Hook–Up
$V_{LD}$, TRANSIENT VOLTAGE (V)
t, TIME (ms)

**Figure 4. Temperature versus $V_{bat}$ for 50% Duty Cycle**

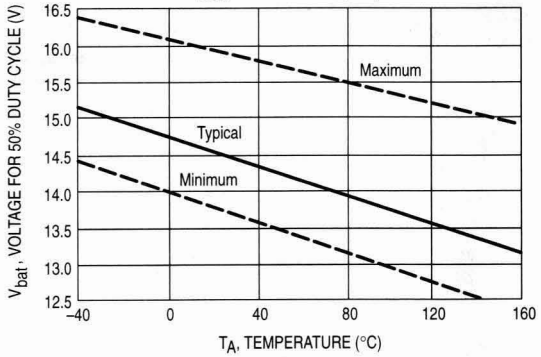



**Figure 5. $V_{bat}$ (50% Duty Cycle) versus $V_{bat}$ (Lamp "On")**

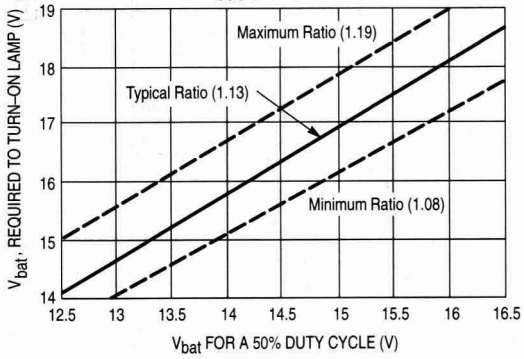



**Figure 6. Field Current versus Cycle Time**

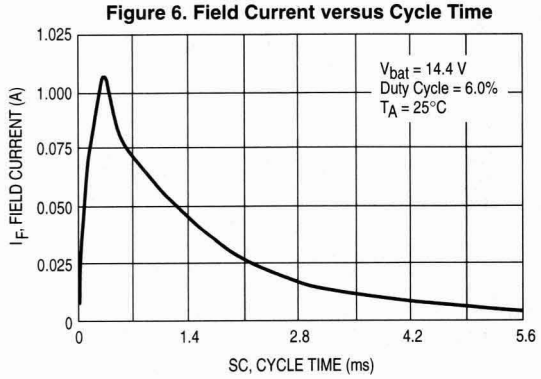



**Figure 7. Field Current versus Time**

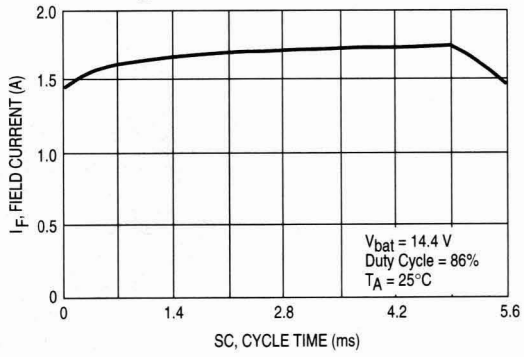



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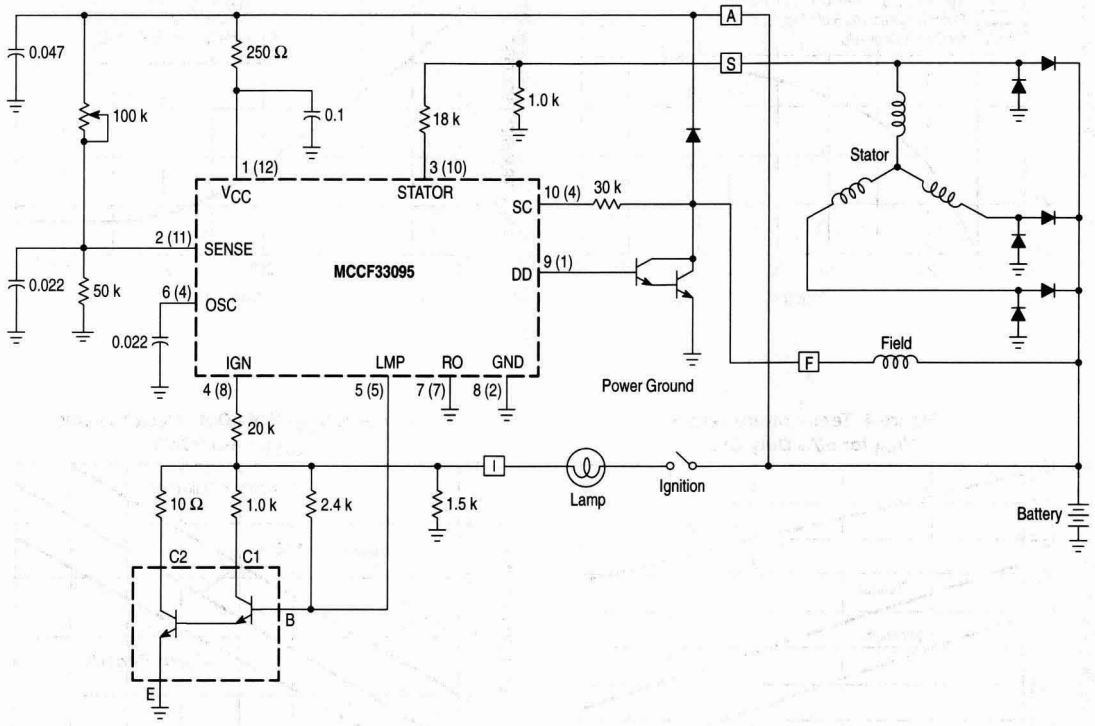
**Figure 8. Integral Alternator Regulator System**

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## FUNCTIONAL DESCRIPTION

### Introduction

This ignition control circuit was originally designed and offered as an MCCF33095 Flip–Chip for use in 12 V automotive alternator charging systems. The MCCF33095 consists of many protection features which are entailed in a ten pin flip–chip package. The device was subsequently made available in a 14 pin surface mount version (MC33095D). Both versions perform in a similar manner. The Flip–Chip version has an advantage over the surface mount version where minimized space and higher operating ambient temperatures are of major concern. Device operation and application suggestions for both versions are given below.

### Oscillator

The oscillator frequency is determined by the value of an external capacitor from the Oscillator pin to ground (see applications circuit). The oscillator frequency in a typical application is approximately 175 Hz, but a range of 50 Hz to 500 Hz can reasonably be used. The waveform generated consists of a positive linear slope followed by relatively fast negative fall (sawtooth). The flip–flops are reset by the falling edge of the sawtooth signal as shown on the logic diagram. The oscillator signal peaks at approximately 3.0 V and provides the timing required for the device.

### Ignition

The Ignition input signal enables the device turn–on when the Ignition pin voltage is greater than 1.4 V. This signal normally originates from the ignition switch of automotive systems.

### Sense

The Sense pin functions as a voltage sensor. It proportionally senses the battery voltage and determines the amount of time the Darlington transistor is high over the next cycle. A low voltage at the Sense pin will result in a long duty cycle for the Darlington while a high voltage produces a short duty cycle. In the application, proportional control is used to determine the duty cycle. Proportional control is defined as the sense ratio of battery voltage, present on the Sense pin, required to obtain a 20% to 95% duty cycle range in the application. The 20% duty cycle value will correlate to the maximum battery in the application. Normally the sense ratio of battery voltage is an end product trim adjustment.

### Lamp

The Lamp output pin functions as a warning indicator for overvoltage and stopped engine or broken belt conditions existing in the system.

### Stator

The Stator pin senses the voltage from the stator in the application circuit, and keeps the device powered up while the stator voltage is high. Furthermore, it acts as a sense for a stopped engine or broken belt condition. If this condition is detected, the Stator turns "on" the Lamp.

### Power Supply, $V_{CC}$

The $V_{CC}$ pin powers the entire device and disables all outputs during any overvoltage condition.

### Roll–Off

The Roll–Off pin provides thermal protection for the circuit. This capability exists, but has not been characterized and is not tested for at this time. Therefore, it is recommended that this pin be connected to ground. The surface mount version has this pin internally connected to ground.

### Darlington Drive

The purpose of the Darlington Drive output pin is to turn on an external power Darlington transistor. The Sense pin voltage determines the duty cycle of the Darlington. The oscillator is set to maintain a minimum duty cycle, except during overvoltage and short circuit conditions.

### Short Circuit

The Short Circuit pin monitors the field voltage. When the Darlington Drive and Short Circuit pins are simultaneously high for a duration greater than the slew rate period, a short circuit condition is noted. The detection time required prevents the device from reacting to false shorts. As a result of short circuit detection, the output is disabled. During a short circuit condition, the device automatically retries with a 2% duty cycle (Darlington "on" time). Once the short circuit condition ceases, normal device operation resumes.

### Application Notes

A capacitor should be used in parallel with the $V_{CC}$ pin to filter out noise transients on the supply or battery line. Likewise, a capacitor should be used in parallel with the Sense pin to create a dominant closed loop pole. Resistors connected to inputs, as mentioned in Notes 1 through 5 of the Electrical Characteristic table, should be used.

## FLIP–CHIP APPLICATION INFORMATION

### Introduction

Although the packaging technology known as "flip–chip" has been available for some time, it has seen few applications outside the automotive and computer industries. Present microelectronic trends are demanding smaller chip sizes, reduced manufacturing costs, and improved reliability. Flip–chip technology satisfies all of these needs.

Conventional assembly techniques involve bonding wires to metal pads to make electrical contact to the integrated circuit. Flip–chip assembly requires further processing of the integrated circuit after final nitride deposition to establish robust solder bumps with which to make electrical contact to the circuit. A spatially identical solderable solder bump pattern, normally formed on ceramic material, serves as a substrate host for the flip–chip. The "bumped" flip–chip is aligned to, and temporarily held in place through the use of soldering paste. The aligned flip–chip and substrate host are placed into an oven and the solder reflowed to establish both electrical and mechanical bonding of the flip–chip to the substrate circuit. Use of solder paste not only holds the chip in temporary placement for reflow but also enhances the reflow process to produce highly reliable bonds.

### Flip–Chip Benefits

Some of the benefits of flip–chip assembly are:

1) Higher circuit density resulting in approximately one–tenth the footprint required of a conventional plastic encapsulated device.
2) Improved reliability, especially in high temperature applications. This is due, in part, to the absence of wires to corrode or fatigue from extensive thermal cycling.
3) No bond wires are required that might possibly become damaged during assembly.
4) Adaptable for simultaneous assembly of multiple flip–chips, in a hybrid fashion, onto a single ceramic substrate.

The following discussion covers the flip–chip process steps performed by Motorola, and the assembly processing required by the customer, in order to attach the flip–chip onto a ceramic substrate.

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## MOTOROLA'S FLIP–CHIP PROCESS

### Overview

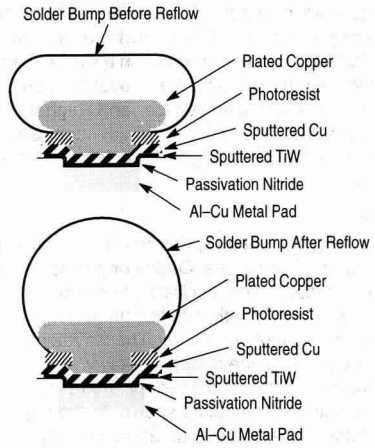
The process steps to develop an integrated circuit flip–chip are identical to that of conventional integrated circuits up to and including the deposition of the final nitride passivation layer on the front surface (circuit side). At this stage all device metal interconnects are present.

The process sequence is as follows:

1) Passivation–nitride photoresist and etch
2) Bimetal sputter (titanium (Ti) and tungsten (W) followed by copper (Cu))
3) Photo mask to define the bump area
4) Copper plate
5) Lead plate
6) Tin plate
7) Photoresist clean to remove all photoresist material
8) Bimetal etchback
9) Reflow for bump formation
10) Final inspection

The diagram below depicts the various layers involved in the bump process.

**Figure 9. Plated Bump Structure and Process Flow**




Initially, photoresist techniques are used to create openings in the nitride passivation layer exposing the metal pad bias. Ti/W, followed by Cu, are sputtered across the entire wafer surface. The surface is then photo patterned to define the bump areas. The sputtered metals together constitute a base metal for the next two metal depositions.

The Ti/W layer provides excellent intermetallic adhesion between the metal pads and the sputtered copper. In addition, the Ti/W provides a highly reliable interface to absorb mechanical shock and vibrations frequently encountered in automotive applications. The sputtered copper layer creates a platform onto which an electroplated copper layer can be built–up. Layers of Cu, Pb, and Sn are applied by plating onto the void areas of the photoresist material. The photoresist is then removed and the earlier sputtered materials are etched away. The flip–chip wafer is then put into an oven exposing it to a specific ambient temperature which causes the lead and tin to ball–up and form a solder alloy.

### IC Solder Bumps

The solder consists of approximately 93% lead and 7% tin. The alloying of lead with tin provides a bump with good ductility and joint adhesion properties. Precise amounts of tin are used in conjunction with lead. Too much tin in relation to lead can cause the solder joints to become brittle and subject to fatigue failure. Motorola has established what it believes to be the optimum material composition necessary in order to achieve high bump reliability.

In the make–up of the flip–chip design, bumps are ideally spaced evenly and symmetrically along each edge of the chip allowing for stress experienced during thermal expansion and vibration to be distributed evenly from bump to bump. The bump dimensions and center–to–center spacing (pitch) are specified by the chip layout and the specific application. The nominal diameter of the bumps is 6.5 mils and the minimum center–to–center pitch is roughly 8.0 mils.

### Reflow

The reflow process creates a thermally induced amalgam of the lead and tin. In the melting process, the surface tension is equalized causing the melted solder to uniformly ball up as mentioned earlier.

The ideal reflow oven profile gradually ramps up in temperature to an initial plateau. The purpose of the plateau is to establish a near equilibrium temperature just below that of the solder's melting temperature. Following the preheat, a short time and higher temperature excursion is necessary. This is to ensure adequate melting of the solder materials. The temperature is then ramped down to room temperature.

An atmosphere of hydrogen is used during the reflow heat cycle. The hydrogen provides a reducing atmosphere for the removal of any surface oxides present. The formation or presence of oxides can cause degradation in the bond reliability of the product.

During the flip–chip attachment reflow onto the ceramic substrate host, the created surface tension of the molten solder aids in the alignment of the chip onto the ceramic substrate.

### Reliability

Motorola is determined to bring high quality and reliable products to its customers. This is being brought about by increased automation, in–line Statistical Process Control (SPC), bump shear strength testing, thermocycling from – 40° to +140°C, process improvements such as backside laser marking of the silicon chip, and improved copper plating techniques.

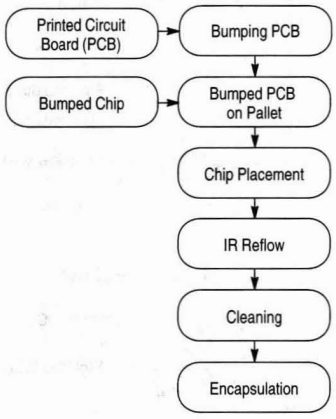
## ATTACHING FLIP–CHIPS ONTO CERAMIC SUBSTRATES

### Overview

The assembly or process of attaching the flip–chip onto a ceramic substrate is performed by the module fabricator. Prior to actual assembly, the ceramic substrate should undergo several process steps. Care should be exercised to properly orient the flip–chip onto the substrate host in order to accommodate the appropriate solder bumps. Ideally, the flip–chip should be removed from the waffle pack with a pick and place machine utilizing a vacuum pick–up to move the die onto the ceramic substrate. Any other components to be reflow soldered onto the substrate can be placed onto the substrate in a similar manner. Flip–chip assembly onto a ceramic substrate allows for some passive components, such as resistors, to be formed directly into the ceramic substrate circuit pattern itself. With all surface components to be mounted in place on the ceramic substrate, the assembly is moved into the furnace where it undergoes a specified temperature variation to solder all the components onto the ceramic substrate. This is accomplished by melting (reflowing) the substrate solder bumps. The resulting assembly should, after being cooled, be cleaned to remove any flux residues. If the substrate assembly is to be mounted into a module, it is recommended that the cavity of the module be filled with an appropriate silicon gel. The use of a gel coating helps to seal the individual components on the substrate from external moisture. A commonly used gel for this purpose is Dow Corning 562. As a final module assembly step, a cover is recommended to be placed over the ceramic assembly for further protection of the circuit.

It should be pointed out that the commonly used ceramic substrate material, though more expensive than other substrate materials, offers significantly superior thermal properties. By comparison, the use of ceramic material offers 33 times the thermal advantage of the second best material, Ceracom. The common FR–4 epoxy material is 100 times less thermally conductive than ceramic. For applications where dielectric constants are important and/or heat dissipation is not of real importance, other less costly materials can be used. The basic concept of the process is identical for all flip–chip substrates used.

**Figure 10. Process Flow Diagram**




### Ceramic Substrate Preparation

The recommended ceramic substrate is aluminum oxide. These substrates come connected in what is referred to as a card. This is identical to the concept of die or chips on a wafer. Each card usually contains 8 to 16 substrates.

Initially, the ceramic should be precleaned with isopropyl alcohol, followed by freon. The bump pattern is then transferred onto the substrate using a metal stencil technique using a palladium silver conducting paste, such as DuPont 9476, through a #325 mesh. Once the pattern is applied, the substrate is dried for ten minutes at 150°C and then fired for 60 minutes at a temperature increasing to a peak of 850°C for ten additional minutes. Solder paste is then stenciled onto the pads.

A metal etched stencil defining the contact areas is recommended. The use of an etched stencil affords better solder paste control than does a silk screen. The metal stencil affords a deposition of a known amount of solder paste, thereby preventing bridging caused by excess solder usage.

### Solder Paste Content

It is recommended that the solder paste consist of 10% tin, 88% lead, and 2% silver alloy. However, 95/3/2 compositions have had successful results.

A rosin based flux, such as RMA (Rosin Mildly Activated) manufactured by Dupont and having spherical particles of 45 to 75 microns, should be used. The tackiness of the solder paste at room temperature helps to hold the flip–chip in place during the pick and place operation. The use of flux:

1) Prevents excess oxidation during reflow.
2) Optimizes the flow of liquid solder through the stencil.
3) Smooths the surface by reducing surface tension, and
4) Enhances the normalization of surface tension upon reflow causing the flip–chip bumps to effectively auto–align themselves to substrate bump pads.

A solder mask can be used for applications requiring high precision as shown in Figures 11a and 11b.

**Figure 11a. Before Reflow**

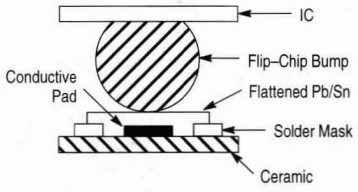
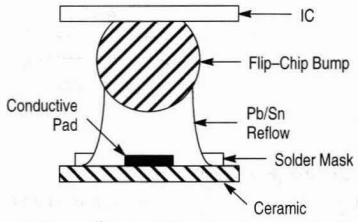


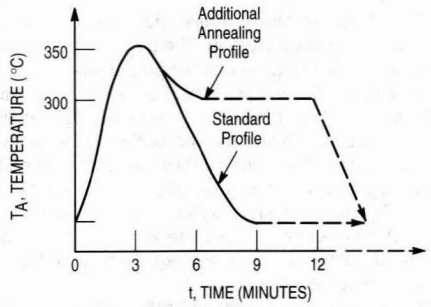

**Figure 11b. After Reflow**




### Oven Profile

After the flip–chip is placed onto the bumped substrate, the substrate and flip–chip are ready for reflow. Initially, the flip–chip is heated to a peak temperature of around 300° to 350°C for five minutes. It is to be noted that the flip–chip bumps have a higher melting temperature than the bumps on the substrate. During assembly reflow, the substrate bumps melt and create a substrate to flip–chip bump bond. After reflow, the assembled part is cooled to room temperature or to some intermediate temperature point for annealing purposes.

**Figure 12. Reflow Oven Profile**




The oven temperature profile is established primarily to melt the solder while minimizing the alloying of the materials and keeping the flux from boiling away. It should be noted that when the flip–chip is placed onto the substrate, the material is stressed in one direction or another. The use of flux helps to reduce any surface stresses present. A reduction in the surface stress enhances solder wetting which in turn aids in the alignment of the flip–chip to the substrate. Poor solder wetting will produce misalignment as well as inferior bond strengths and reliability.

It is recommended that an inert atmosphere such as nitrogen be used during the reflow process to prevent oxidation.

### Final Cleaning

The final cleaning involves removing the remaining flux from the flip–chip assembly. Three possible methods of removing flux are: ultrasonic cleaner, Terpene solvent and DI water, or vapor degreaser. The flux manufacturer should be able to recommend the proper type of vapor degreaser to be used.

### Test and Reliability

Both visual inspection and shear strength testing should be performed on packaged flip–chip assemblies.

Solder reflow results that exhibit a grainy and dull appearance produce inferior bond shear strengths. Inferior bond shear strengths are visually recognizable by:

1) The presence of old or badly oxidized solder paste.
2) Insufficient amount of solderable material.
3) The contamination of bond pads with grease, oil, etc.

It should be mentioned that many contaminants are transparent and not easily detectable by visual means.

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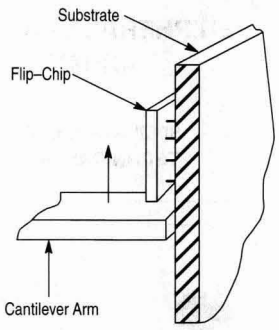
Shear strength testing should meet a 0.8 Newtons/Bump criteria. Shear strength testing should follow thermocycling of the chip from – 40° to +140°C to insure the stability of shear strength over temperature. Figure 13 depicts a test set–up which might possibly be used.

**Figure 13. Shear Test Fixture**




Aside from physical contamination, flip–chips, like any other chips, should not be handled directly due to the fact that electrostatic discharges can cause permanent damage to the electronic circuit. Flip–chips which do survive an electrostatic discharge can be left in a weakened condition resulting in reduced reliability of the end product. To avoid electrostatic damage of the circuit, assembly personnel should make use of a wrist strap or some other device to provide electrostatic grounding of their body. For the same reason, machinery used to assemble semiconductor circuits should be electrostaticly grounded.

Flip–chips rely primarily on the thermal path established by the bumps to remove heat from the chip as a result of internal circuit operation. Standard Motorola flip–chips have a thermal resistance of approximately 290°C/W/Bump. This figure can be used to estimate the allowed maximum power dissipation of the chip.

**Cost and Equipment Manufacturers**

The cost of implementing a flip–chip assembly process depends on the specific production requirements and as a result will vary over a broad range. It is possible to implement a small volume laboratory set–up for a few hundred dollars using manual operations. At the other end of the scale one could spend millions setting up a fully automated line incorporating pattern recognization, chip and substrate orientation, reflow, cleaning, and test. The module fabricator will have to make this assessment.

An assembly operator can manually accomplish the pick and place operation using a vacuum probe to pick–up and orient the flip–chip onto the substrate. Furthermore, it is possible to perform the reflow assembly operation using a simple batch process oven fabricated from a laboratory hot plate. However, the use of such process techniques will have questionable impact on the final product's reliability and quality. For this reason, it is highly recommended that the module fabricator seriously consider two major pieces of equipment; a pick and place machine and an infrared solder reflow oven. Both pieces of equipment can vary over a wide cost range depending on the production requirements. A partial list of manufacturers for this equipment is given below.

Pick and Place Machine:

Universal Instruments Corp.
Dover Technologies, Inc.
Binghamton, NY 13902
(607) 772–7522

Seiko
Torrance, CA 90505
(310) 517–7850

Laurier Inc.
Hudson, NH 03051
(603) 889–8800

Infrared Reflow Oven:

BTU
Bellerica, MA 01862
(508) 667–4111

Vitronics
Newmarket, NH 03857
(603) 659–6550

**Additional Applications**

Completed ceramic flip–chip sub–assemblies can be stacked one on top of another to produce an overall assembly by making contact connections through bumps. This technology is beginning to emerge in the computer industry where physical module size is of significant importance. Furthermore, this assembly technology, though more complex, is undergoing serious consideration within the automotive industry as well.

Applications requiring small size and high reliability at high ambient temperatures can benefit considerably through the implementation of flip–chip assembly techniques.

MOTOROLA

# TCF6000

## Peripheral Clamping Array

The TCF6000 was designed to protect input/output lines of microprocessor systems against voltage transients.

- Optimized for HMOS System
- Minimal Component Count
- Low Board Space Requirement
- No P.C.B. Track Crossovers Required
- Applications Areas Include Automotive, Industrial, Telecommunications and Consumer Goods

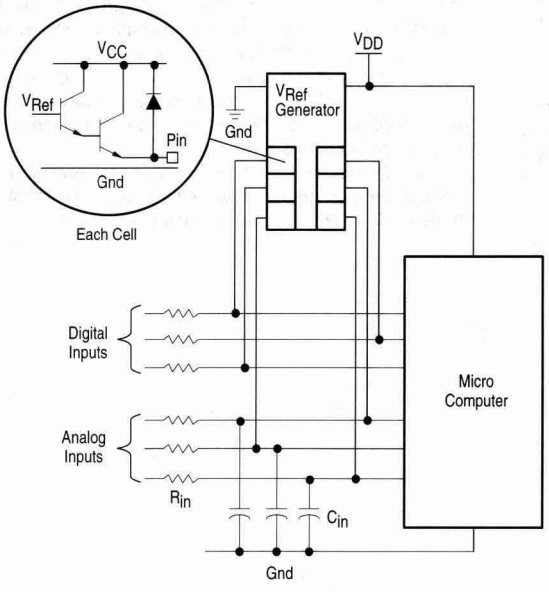
**PERIPHERAL CLAMPING ARRAY**

**SEMICONDUCTOR TECHNICAL DATA**

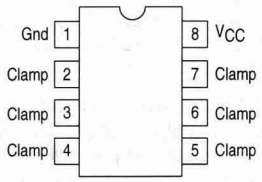
**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**NO SUFFIX**
PLASTIC PACKAGE
CASE 626

**Figure 1. Representative Block Diagram and Simplified Application**




**PIN CONNECTIONS**




**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| TCF6000D | $T_A$ = – 40° to +85°C | SO–8 |
| TCF6000 | | Plastic DIP |

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**MAXIMUM RATINGS** ($T_A$ = 25°C, unless otherwise noted, Note 1.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 6.0 | V |
| Supply Current | $I_i$ | 300 | mA |
| Clamping Current | $I_{IK}$ | ±50 | mA |
| Junction Temperature | $T_J$ | 150 | °C |
| Power Dissipation ($T_A$ = + 85°C) | $P_D$ | 400 | m/W |
| Thermal Resistance (Junction–Ambient) | $\theta_{JA}$ | 100 | °C/W |
| Operating Ambient Temperature Range | $T_A$ | –40 to +85 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to + 150 | °C |

**NOTE:** 1. Values beyond which damage may occur.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C, 4.5 ≤ $V_{CC}$ ≤ 5.5 V, unless otherwise noted.)

| Characteristics | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Positive Clamping Voltage (Note 2)<br>($I_{IK}$ = 10 mA, –40°C ≤ $T_A$ ≤ + 85°C) | $V_{(IK)}$ | – | $V_{CC}$ + 1.0 | V |
| Positive Peak Clamping Current | $I_{IK(P)}$ | – | 20 | mA |
| Negative Peak Clamping Voltage<br>($I_{IK}$ = –10 mA, –40°C ≤ $T_A$ ≤ + 85°C) | $V_{(IK)}$ | –0.3 | – | V |
| Negative Peak Clamping Current | $I_{IK(P)}$ | –20 | – | mA |
| Output Leakage Current<br>(0 V ≤ $V_{in}$ ≤ $V_{CC}$)<br>(0 V ≤ $V_{in}$ ≤ $V_{CC}$, –40°C ≤ $T_A$ ≤ + 85°C) | <br>$I_L$<br>$I_{LT}$ | <br>–<br>– | <br>1.0<br>5.0 | µA |
| Channel Crosstalk ($A_{CT}$ = 20 log $I_L/I_{IK}$) | $A_{CT}$ | 100 | – | dB |
| Quiescent Current (Package) | $I_B$ | – | 2.0 | mA |

**NOTE:** 2. The device might not give 100% protection in CMOS applications.

## CIRCUIT DESCRIPTION

To ensure the reliable operation of any integrated circuit based electronics system, care has been taken that voltage transients do not reach the device I/O pins. Most NMOS, HMOS and Bipolar integrated circuits are particularly sensitive to negative voltage peaks which can provoke latch–up or otherwise disturb the normal functioning of the circuit, and in extreme cases may destroy the device.

Generally the maximum rating for a negative voltage transients on integral circuits is –0.3 V over the whole temperature range. Classical protection units have consisted of diode/resistor networks as shown in Figures 2a and 2b.

The arrangement in Figure 2a does not, in general, meet the specification and is therefore inadequate.

The problem with the solution shown if Figure 2b lies mainly with the high current drain through the biassing devices $R_1$ and $D_3$. A second problem exists if the input line carries an analog signal. When $V_{in}$ is close to the ground potential, currents arising from leakage and mismatch between $D_3$ and $D_2$ can be sourced into the input line, thus disturbing the reading.

**Figure 2. Classical Protection Circuits**

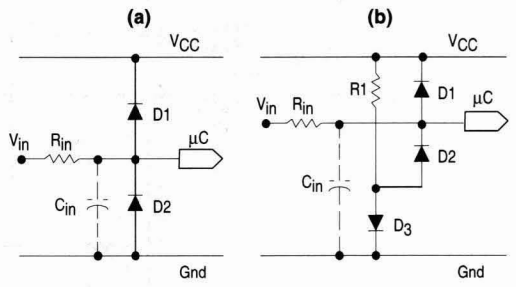


Figure 3 shows the clamping characteristics which are common to each of the six cells in the Peripheral Clamping Array.

As with the classical protection circuits, positive voltage transients are clamped by means of a fast diode to the $V_{CC}$ supply line.

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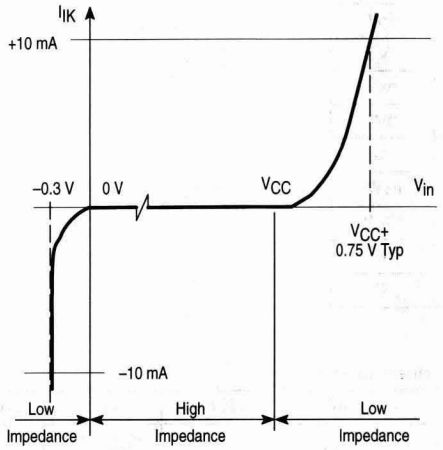
**Figure 3. Clamping Characteristics**




## APPLICATIONS INFORMATION

Figure 4 depicts a typical application in a microcomputer based automotive ignition system.

The TCF6000 is being used not only to protect the system's normal inputs but also the (bidirectional) serial diagnostics port.

The value of the input resistors, $R_{in}$, is determined by the clamping current and the anticipated value of the spikes.

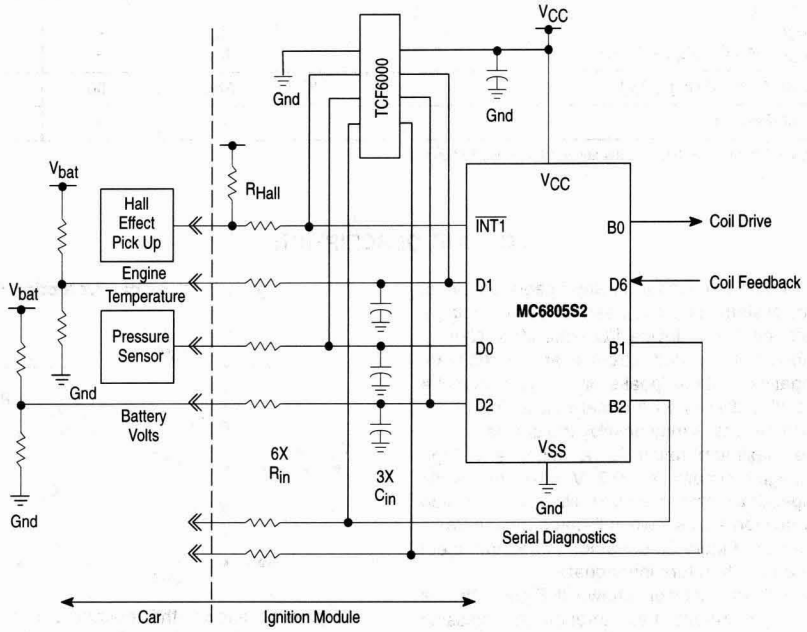
Thus:

$$R_{in} = \frac{V}{I_{IK}}\ \Omega$$

where: V = Peak Volts (V)
$I_{IK}$ = Clamping current (A)
So, taking, V = 300 V typically (SAE J1211)
$I_{IK}$ = 10 mA (recommended)
gives, $R_{in}$ = 30 k

Resistors of this value will not usually cause any problems in MOS systems, but their presence needs to be taken into account by the designer. Their effect will normally need to be compensated for Bipolar systems.

**Figure 4. Typical Automotive Application**

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The use of $C_{in}$ is not mandatory, and is not recommended where the lines to be protected are used for output or for both input and output. For digital input lines, the use of a small capacitor in the range of 50 pF to 220 pF is recommended as this will reduce the rate of rise of voltage seen by the TCF6000 and hence the possibility of overshoot.

In the case of the analog inputs, such as that from the pressure sensor, the capacitor $C_{in}$ is necessary for devices such as the MC6805S2 shown, which present a low impedance during the sampling period. The maximum value for $C_{in}$ is determined by the accuracy required, the time taken to sample the input and the input impedance during that time, while the maximum value is determined by the required frequency response and the value of $R_{in}$.

Thus for a resistive input A/D connector where:

$T_S$ = Sample time (seconds)
$R_D$ = Device input resistance (Ω)
$V_{in}$ = Input voltage (V)
k = Required accuracy (%)
$Q_1$ = Charge on capacitor before sampling
$Q_2$ = Charge on capacitor after sampling
$I_D$ = Device input current (A)

Thus: $Q_1 - Q_2 = \frac{k \times Q_1}{100}$

but, $Q_1 = C_{in}\, V_{in}$

and, $Q_1 - Q_2 = I_D \bullet T_S$

so that, $I_D\, T_S = \frac{k \bullet C_{in} - V_{in}}{100}$

and, $C_{in}\,(min) = \frac{I_D \bullet T_S}{V_{in} \bullet k}$ Farad

so, $C_{in}\,(min) = \frac{100 \bullet T_S}{k \bullet R_D}$ Farad

The calculation for a sample and hold type converter is even simpler:

k = Required accuracy (%)
$C_H$ = Hold capacitor (Farad)

$C_{in}\,(min) = \frac{100 \bullet C_H}{k}$ Farad

For the MC6805S2 this comes out at:

$C_{in}\,(min) = \frac{100.25\ pF}{0.25}$ = 10 nF for 1/4% accuracy

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MOTOROLA

# UAA1041B

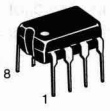
# Automotive Direction Indicator

This device was designed for use in conjunction with a relay in automotive applications. It is also applicable for other warning lamps such as "handbrake ON," etc.

- Defective Lamp Detection
- Overvoltage Protection
- Short Circuit Detection and Relay Shutdown to Prevent Risk of Fire
- Reverse Battery Connection Protection
- Integrated Suppression Clamp Diode

**AUTOMOTIVE DIRECTION INDICATOR**

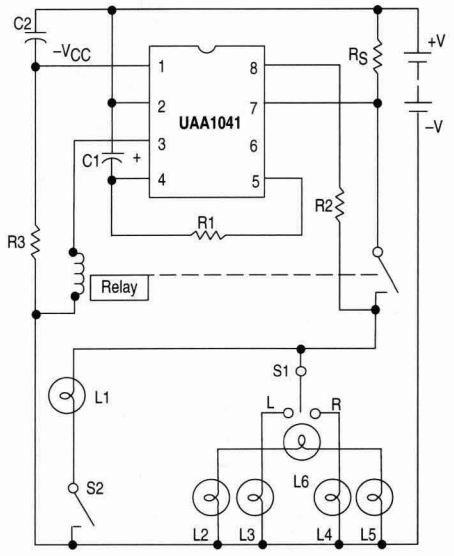
**SEMICONDUCTOR TECHNICAL DATA**




**NO SUFFIX**
PLASTIC PACKAGE
CASE 626

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

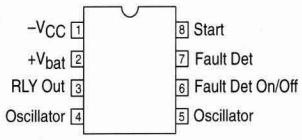
**Figure 1. Typical Automotive System**




L1: 1.2 W, warning light handbrake ON
L2, L3, L4, L5: 21 W, turn signals

R1 = 75 k
R2 = 3.3 k
R3 = 220 Ω
RS = 30 mΩ
C1 = 5.6 µF
C2 = 0.047 µF

**PIN CONNECTIONS**




(Top View)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| UAA1041BD | $T_A$ = – 40° to +100°C | SO–8 |
| UAA1041B | | Plastic DIP |

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## MAXIMUM RATINGS

| Rating | Pin | Value | Unit |
|---|---|---|---|
| Current: Continuous/Pulse* | 1<br><br>2<br>3<br>8 | +150/+500<br>–35/–500<br>±350/1900<br>±300/1400<br>±25/50 | mA |
| Junction Temperature | $T_J$ | 150 | °C |
| Operating Ambient Temperature Range | $T_A$ | –40 to + 100 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to + 150 | °C |
| Thermal Resistance, Junction–to–Ambient | $R_{\theta JA}$ | 100 | °C/W (Typ) |

* One pulse with an exponential decay and with a time constant of 500 ms.

## ELECTRICAL CHARACTERISTICS ($T_1$ = 25°C)

| Characteristics | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Battery Voltage Range (normal operation) | | $V_B$ | 8.0 | – | 18 | V |
| Overvoltage Detector Threshold | ($V_{Pin2}$–$V_{Pin1}$) | $D_{th(OV)}$ | 19 | 20.2 | 21.5 | V |
| Clamping Voltage | ($V_{Pin2}$–$V_{Pin1}$) | $V_{IK}$ | 29 | 31.5 | 34 | V |
| Short Circuit Detector Threshold | ($V_{Pin2}$–$V_{Pin7}$) | $D_{th(SC)}$ | 0.63 | 0.7 | 0.77 | V |
| Output Voltage ($I_{relay}$ = –250 mA) | ($V_{Pin2}$–$V_{Pin3}$) | $V_O$ | – | – | 1.5 | V |
| Starter Resistance $R_{st} = R_2 + R_{Lamp}$ | | $R_{st}$ | – | – | 3.6 | kΩ† |
| Oscillator Constant (normal operation) | | Kn | 1.4 | 1.5 | 1.6 | – |
| Temperature Coefficient of Kn | | Kn | – | $-1.5x10^{-3}$ | – | 1/°C |
| Duty Cycle (normal operation) | | – | 45 | 50 | 55 | % |
| Oscillator Constant – (1 lamp defect of 21 W) | | $K_F$ | 0.63 | 0.68 | 0.73 | – |
| Duty Cycle (1 lamp defect of 21 W) | | – | 35 | 40 | 45 | % |
| Oscillator Constant | | K1<br>K2<br>K3 | 0.167<br>0.25<br>0.126 | 0.18<br>0.27<br>0.13 | 0.193<br>0.29<br>0.14 | – |
| Current Consumption (relay off)<br>Pin 1; at $V_{Pin2} - V_{Pin1}$ = 8.0 V<br>= 13.5 V<br>= 18 V | | $I_{CC}$ | <br>–<br>–2.5<br>– | <br>–0.9<br>–1.6<br>–2.2 | <br>–<br>–1.0<br>– | mA |
| Current Consumption (relay on)<br>Pin 1; at $V_{Pin2} - V_{Pin1}$ = 8.0 V<br>= 13.5 V<br>= 18 V | | – | <br>–<br>–<br>– | <br>–3.8<br>–5.6<br>–6.9 | <br>–<br>–<br>– | mA |
| Defect Lamp Detector Threshold at $V_{Pin2}$ to $V_B$ = 8.0 V<br>and $R_3$ = 220 Ω = 13.5 V<br>= 18 V | | <br>$V_{Pin2}$–$V_{Pin7}$<br>$V_{Pin2}$–$V_{Pin7}$<br>$V_{Pin2}$–$V_{Pin7}$ | –<br>79<br>– | 68<br>85.3<br>100 | –<br>91<br>– | mV |

† See Note 1 of Application Information

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## CIRCUIT DESCRIPTION

The circuit is designed to drive the direction indicator flasher relay. Figure 2 shows the typical system configuration with the external components. It consists of a network (R1, C1) to determine the oscillator frequency, shunt resistor ($R_S$) to detect defective bulbs and short circuits in the system, and two current limiting resistors ($R_2$/$R_3$) to protect the IC against load dump transients. The circuit can be used either with or without short circuit detection, and features overvoltage, defective lamp and short circuit detection.

The lightbulbs L2, L3, L4, L5 are the turn signal indicators with the dashboard–light L6. When switch S1 is closed, after a time delay of $t_1$ (in our example $t_1$ = 75 ms), the relay will be actuated. The corresponding lightbulbs (L2, L3 or L4, L5) will flash at the oscillator frequency, independent of the battery voltage of 8.0 V to 18 V. The flashing cycle stops and the circuit is reset to the initial position when switch S1 is open.

### Overvoltage Detection

Senses the battery voltage. When this voltage exceeds 20.2 V (this is the case when two batteries are connected in series), the relay will be turned off to protect the lightbulbs.

### Lightbulb Defect Detector

Senses the current through the shunt resistor $R_S$. When one of the lightbulbs is defective, the failure is indicated by doubling the flashing frequency.

### Short Circuit Detector

Detects excessive current ($I_{sh}$ > 25 A) flowing in the shunt resistor $R_S$. The detection takes place after a time delay of $t_3$ ($t_3$ = 55 ms). In this case, the relay will be turned off. The circuit is reset by switching S1 to the off position.

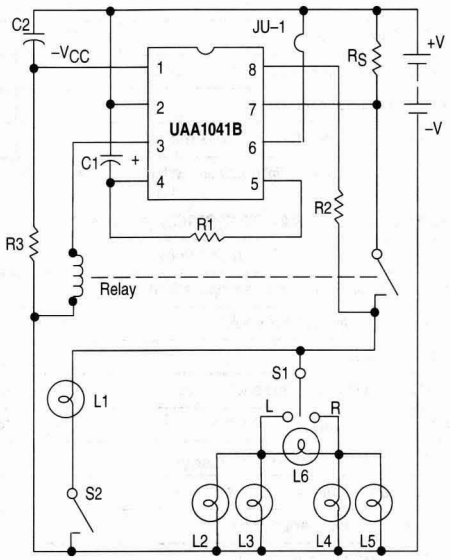
### Operation with Short Circuit Detection

Pin 6 has to be left open and a capacitor $C_2$ has to be connected between Pin 1 and Pin 2.

### Operation without Short Circuit Detection

Pin 6 has to be connected to Pin 2, and the use of capacitor $C_2$ is not necessary. The circuit can also be used for other warning flashers. In this example, when the handbrake is engaged, it is signaled by the light (L1).

**Figure 2. Typical System Configuration**




**PARTS LIST**

| | |
|---|---|
| R1 = 75 kΩ | Relay–Coil Resistance |
| R2 = 3.3 kΩ | Range 60 Ω to 800 Ω |
| R3 = 220 Ω | |
| $R_S$ = 30 mΩ | Note: Per text connect |
| Wire Resistor | jumper JU–1 bypass |
| C1 = 5.6 µF | short circuit detector |
| C2 = 0.047 µF | C2 may be deleted also. |

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## APPLICATION INFORMATION

1. The flashing cycle is started by closing S1. The switch position is sensed across resistor $R_2$ and $R_{Lamp}$ by Input 8.

   $$R_{st} = R_2 + R_{Lamp}.$$

   The condition for the start is: $R_{st}$ < 3.6 kΩ.
   For correct operation, leakage resistance from Pin 8 to ground must be greater than 5.6 kΩ.

2. Flashing frequency: $f_n = \frac{1}{R_1 C_1 K_n}$

3. Flashing frequency in the case of one defective lightbulb of 21 W:

   $$f_F = \frac{1}{R_1 C_1 K_F} \quad K_n = 2{,}2K_F$$

4. $t_1$: delay at the moment when S1 is closed and first flash
   $t_1 = K_1 R_1 C$
5. $t_2$: defective lightbulb detection delay $t_2 = K_2 R_1 C_1$
6. $t_3$: short circuit detection delay $t_3 = K_1 R_1 C_1$
   In the case of short circuit – it is assumed that the voltage ($V_{Pin2}$–$V_{Pin1}$) ≥ 8.0 V. The relay will be turned off after delay $t_3$. The circuit is reset by switching S1 to the off position. The capacitor C2 is not obligatory when the short circuit
7. detector is not used. In this case Pin 6 has to be connected to Pin 2.
   When overvoltage is sensed ($V_{Pin2} – V_{Pin1}$) the relay is
8. turned off to protect the relay and the lightbulbs against excessive currents.

# Other Analog Circuits

## In Brief . . .

Other analog circuits are provided for special applications with both bipolar and CMOS technologies. These circuits range from the industry standard analog timing circuits and multipliers to specialized CMOS smoke detectors. These products provide key functions in a wide range of applications, including data transmission, commercial smoke detectors, and various industrial controls.


| | Page |
|---|---|
| Timing Circuits | 11–2 |
| Singles | 11–2 |
| Duals | 11–2 |
| Multipliers | 11–2 |
| Linear Four-Quadrant Multipliers | 11–2 |
| Smoke Detectors (CMOS) | 11–3 |
| Package Overview | 11–4 |
| Device Listing | 11–5 |

# Timing Circuits

These highly stable timers are capable of producing accurate time delays or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free–running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The output structure can source or sink up to 200 mA or drive TTL circuits. Timing intervals from microseconds through hours can be obtained. Additional terminals are provided for triggering or resetting if desired.

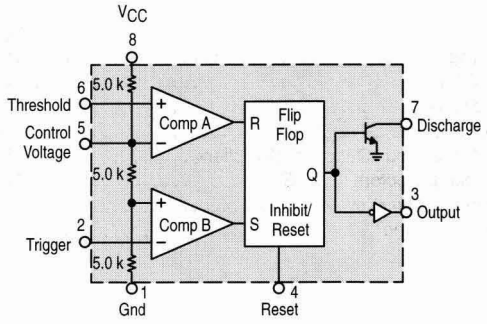
## Singles

**MC1455P1, D**

$T_A$ = 0° to +70°C, Case 626, 751

**MC1455BP1, D**

$T_A$ = −40° to +85°C, Case 626, 751




## Duals

**MC3456P**

$T_A$ = 0° to +70°C, Case 646

**NE556N, D**

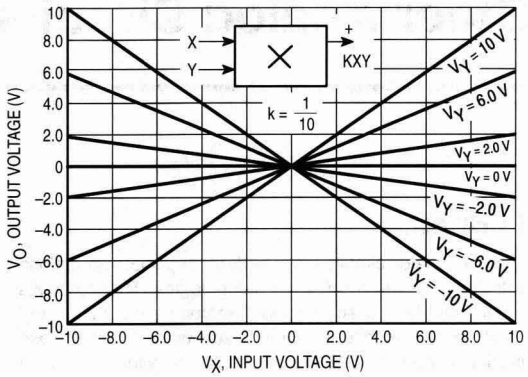
$T_A$ = 0° to +70°C, Case 646, 751A

# Multipliers

## Linear Four–Quadrant Multipliers

Multipliers are designed for use where the output voltage is a linear product of two input voltages. Typical applications include: multiply, divide, square, root–mean–square, phase detector, frequency doubler, balanced modulator/demodulator, electronic gain control.

**Multiplier Transfer Characteristics**




**MC1494P**

$T_A$ = 0° to +70°C, Case 648

This device has all the necessary internal regulation and references. The single–ended output is referenced to ground.

**MC1495D, P**

$T_A$ = 0° to +70°C, Case 751A, 646

Maximum versatility is assured by allowing the user to select the level shift method.

**MC1495BP**

$T_A$ = −40° to +125°C, Case 646

Linearity and offset are actually tested over temperature. This is an improved specification over previous versions.

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# Smoke Detectors (CMOS)

These smoke detector ICs require a minimum number of external components. When smoke is sensed, or a low battery voltage is detected, an alarm is sounded via an external piezoelectric transducer. All devices are designed to comply with UL specifications.

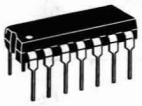
**Table 1. Smoke Detectors (CMOS)**

| Function | Recommended Power Source | Unique Feature | Low Battery Detector | Piezoelectric Horn Driver | Complies with UL217 and UL268 | Device Number | Suffix/ Package |
|---|---|---|---|---|---|---|---|
| Ionization–Type Smoke Detector | Battery | High Input Impedance FET Comparator | ✓ | ✓ | ✓ | MC14467–1 | P1/646 |
| | Line | | – | – | ✓ | MC14578 | P/648 |
| Ionization–Type Smoke Detector with Interconnect | Battery | | ✓ | ✓ | ✓ | MC14468 | |
| | Line | | – | ✓ | ✓ | MC14470 | |
| Photoelectric–Type Smoke Detector with Interconnect | Battery | Photo Amplifier | ✓ | ✓ | ✓ | MC145010 | P/648, DW/751G |
| | Line | | (1) | ✓ | ✓ | MC145011 | |

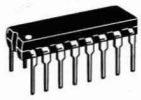
(1) Low–supply detector.

# Other Analog Circuits Package Overview

CASE 626
P1 SUFFIX



CASE 646
N, P, P1 SUFFIX



CASE 648
P SUFFIX

CASE 751
D SUFFIX

CASE 751A
D SUFFIX

CASE 751G
DW SUFFIX

11

# Device Listing

## Timing Circuits


| Device | Function | Page |
|---|---|---|
| MC1455, B | Timing Circuit | 11–6 |
| MC3456 | Dual Timing Circuit | 11–43 |


## Multipliers


| Device | Function | Page |
|---|---|---|
| MC1494 | Linear Four-Quadrant Multiplier | 11–14 |
| MC1495 | Wideband Linear Four-Quadrant Multiplier | 11–28 |
| MC1496 | Balanced Modulator/Demodulator Four-Quadrant Multiplier | (See Chapter 8) |

MOTOROLA

# MC1455, B

# Timing Circuit

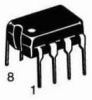
The MC1455 monolithic timing circuit is a highly stable controller capable of producing accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode, time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free–running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200 mA or drive MTTL circuits.

- Direct Replacement for NE555 Timers
- Timing from Microseconds through Hours
- Operates in Both Astable and Monostable Modes
- Adjustable Duty Cycle
- High Current Output Can Source or Sink 200 mA
- Output Can Drive MTTL
- Temperature Stability of 0.005% per °C
- Normally ON or Normally OFF Output

**TIMING CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

**P1 SUFFIX**
PLASTIC PACKAGE
CASE 626

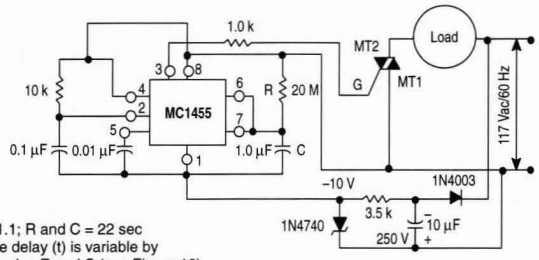


**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)

**ORDERING INFORMATION**

| Device | Operating Temperature Range | Package |
|---|---|---|
| MC1455P1 | $T_A$ = 0° to +70°C | Plastic DIP |
| MC1455D | | SO–8 |
| MC1455BD | $T_A$ = – 40° to +85°C | SO–8 |
| MC1455BP1 | | Plastic DIP |

**Figure 1. 22 Second Solid State Time Delay Relay Circuit**




t = 1.1; R and C = 22 sec
Time delay (t) is variable by changing R and C (see Figure 16).

**Figure 2. Representative Block Diagram**

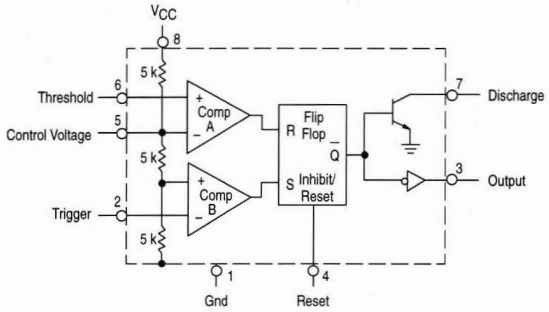
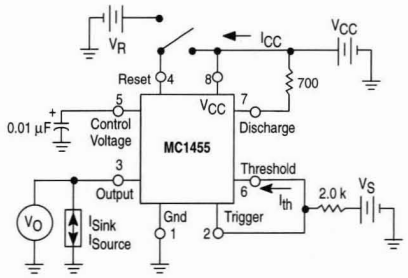



**Figure 3. General Test Circuit**




Test circuit for measuring DC parameters (to set output and measure parameters):
a) When $V_S \geq 2/3\ V_{CC}$, $V_O$ is low.
b) When $V_S \leq 1/3\ V_{CC}$, $V_O$ is high.
c) When $V_O$ is low, Pin 7 sinks current. To test for Reset, set $V_O$ high, apply Reset voltage, and test for current flowing into Pin 7. When Reset is not in use, it should be tied to $V_{CC}$.

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**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | +18 | Vdc |
| Discharge Current (Pin 7) | $I_7$ | 200 | mA |
| Power Dissipation (Package Limitation)<br>P1 Suffix, Plastic Package<br>Derate above $T_A$ = +25°C<br>D Suffix, Plastic Package<br>Derate above $T_A$ = +25°C | <br>$P_D$<br><br>$P_D$<br> | <br>625<br>5.0<br>625<br>160 | <br>mW<br>mW/°C<br>mW<br>°C/W |
| Operating Temperature Range (Ambient)<br>MC1455B<br>MC1455 | $T_A$ | <br>–40 to +85<br>0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = +25°C, $V_{CC}$ = +5.0 V to +15 V, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Operating Supply Voltage Range | $V_{CC}$ | 4.5 | – | 16 | V |
| Supply Current<br>$V_{CC}$ = 5.0 V, $R_L$ = ∞<br>$V_{CC}$ = 15 V, $R_L$ = ∞, Low State (Note 1) | $I_{CC}$ | <br>–<br>– | <br>3.0<br>10 | <br>6.0<br>15 | mA |
| Timing Error (R = 1.0 kΩ to 100 kΩ) (Note 2)<br>Initial Accuracy C = 0.1 µF<br>Drift with Temperature<br>Drift with Supply Voltage | | <br>–<br>–<br>– | <br>1.0<br>50<br>0.1 | <br>–<br>–<br>– | <br>%<br>PPM/°C<br>%/V |
| Threshold Voltage/Supply Voltage | $V_{th}/V_{CC}$ | – | 2/3 | – | |
| Trigger Voltage<br>$V_{CC}$ = 15 V<br>$V_{CC}$ = 5.0 V | $V_T$ | <br>–<br>– | <br>5.0<br>1.67 | <br>–<br>– | V |
| Trigger Current | $I_T$ | – | 0.5 | – | µA |
| Reset Voltage | $V_R$ | 0.4 | 0.7 | 1.0 | V |
| Reset Current | $I_R$ | – | 0.1 | – | mA |
| Threshold Current (Note 3) | $I_{th}$ | – | 0.1 | 0.25 | µA |
| Discharge Leakage Current (Pin 7) | $I_{dischg}$ | – | – | 100 | nA |
| Control Voltage Level<br>$V_{CC}$ = 15 V<br>$V_{CC}$ = 5.0 V | $V_{CL}$ | <br>9.0<br>2.6 | <br>10<br>3.33 | <br>11<br>4.0 | V |
| Output Voltage Low<br>$I_{Sink}$ = 10 mA ($V_{CC}$ = 15 V)<br>$I_{Sink}$ = 50 mA ($V_{CC}$ = 15 V)<br>$I_{Sink}$ = 100 mA ($V_{CC}$ = 15 V)<br>$I_{Sink}$ = 200 mA ($V_{CC}$ = 15 V)<br>$I_{Sink}$ = 8.0 mA ($V_{CC}$ = 5.0 V)<br>$I_{Sink}$ = 5.0 mA ($V_{CC}$ = 5.0 V) | $V_{OL}$ | <br>–<br>–<br>–<br>–<br>–<br>– | <br>0.1<br>0.4<br>2.0<br>2.5<br>–<br>0.25 | <br>0.25<br>0.75<br>2.5<br>–<br>–<br>0.35 | V |
| Output Voltage High<br>$V_{CC}$ = 15 V ($I_{Source}$ = 200 mA)<br>$V_{CC}$ = 15 V ($I_{Source}$ = 100 mA)<br>$V_{CC}$ = 5.0 V ($I_{Source}$ = 100 mA) | $V_{OH}$ | <br>–<br>12.75<br>2.75 | <br>12.5<br>13.3<br>3.3 | <br>–<br>–<br>– | V |
| Rise Time Differential Output | $t_r$ | – | 100 | – | ns |
| Fall Time Differential Output | $t_f$ | – | 100 | – | ns |

**NOTES:** 1. Supply current when output is high is typically 1.0 mA less.
2. Tested at $V_{CC}$ = 5.0 V and $V_{CC}$ = 15 V Monostable mode.
3. This will determine the maximum value of $R_A + R_B$ for 15 V operation. The maximum total R = 20 mΩ.

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**Figure 4. Trigger Pulse Width**

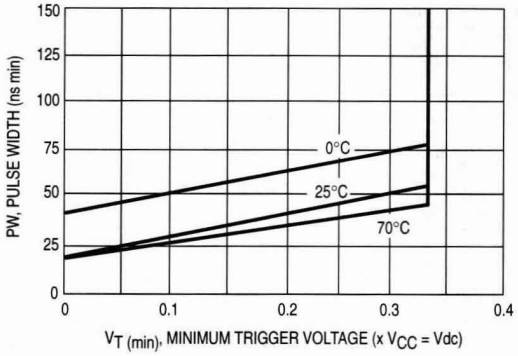


**Figure 5. Supply Current**

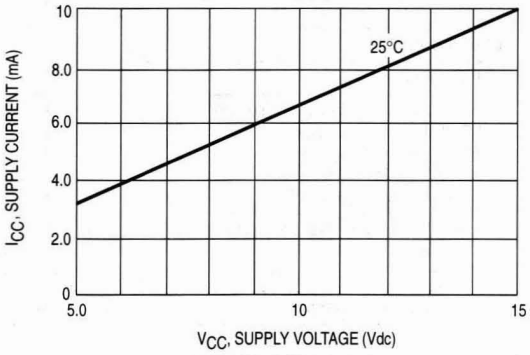


**Figure 6. High Output Voltage**

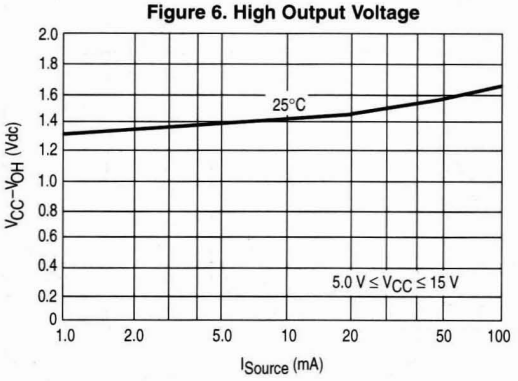


**Figure 7. Low Output Voltage @ $V_{CC}$ = 5.0 Vdc**

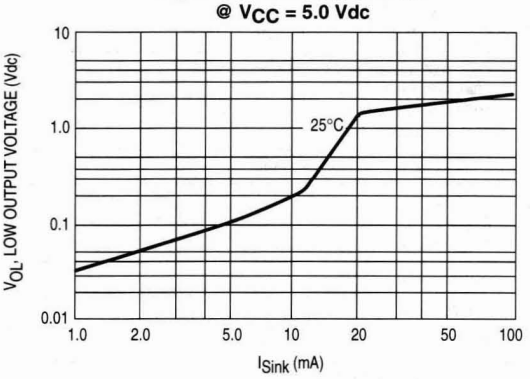


**Figure 8. Low Output Voltage @ $V_{CC}$ = 10 Vdc**

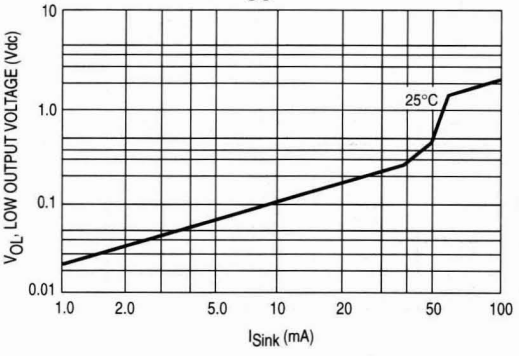


**Figure 9. Low Output Voltage @ $V_{CC}$ = 15 Vdc**

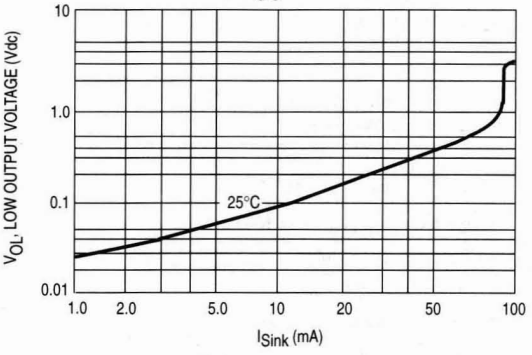


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**Figure 10. Delay Time versus Supply Voltage**

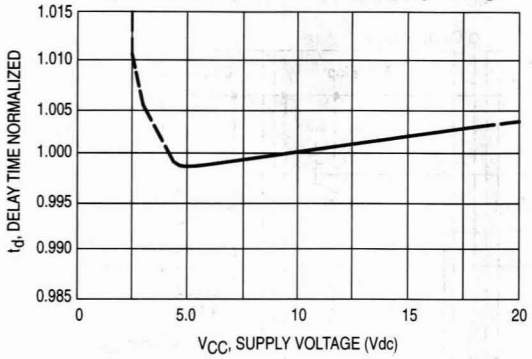


**Figure 11. Delay Time versus Temperature**

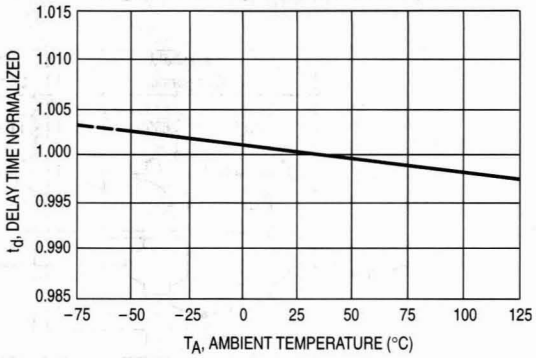


**Figure 12. Propagation Delay versus Trigger Voltage**

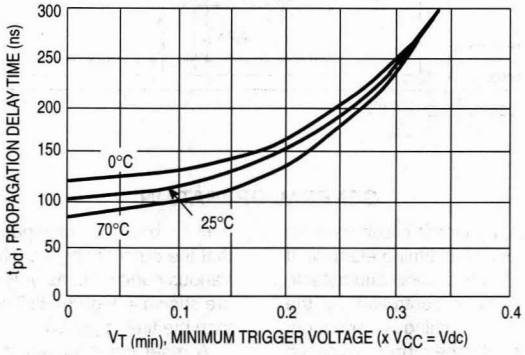


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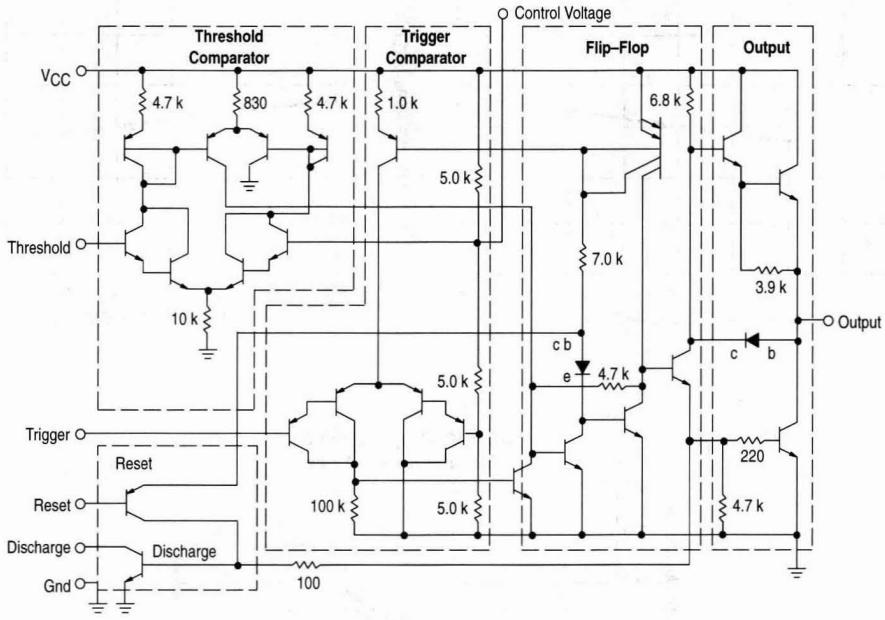
**Figure 13. Representative Circuit Schematic**




## GENERAL OPERATION

The MC1455 is a monolithic timing circuit which uses an external resistor – capacitor network as its timing element. It can be used in both the monostable (one–shot) and astable modes with frequency and duty cycle controlled by the capacitor and resistor values. While the timing is dependent upon the external passive components, the monolithic circuit provides the starting circuit, voltage comparison and other functions needed for a complete timing circuit. Internal to the integrated circuit are two comparators, one for the input signal and the other for capacitor voltage; also a flip–flop and digital output are included. The comparator reference voltages are always a fixed ratio of the supply voltage thus providing output timing independent of supply voltage.

### Monostable Mode

In the monostable mode, a capacitor and a single resistor are used for the timing network. Both the threshold terminal and the discharge transistor terminal are connected together in this mode (refer to circuit in Figure 14). When the input voltage to the trigger comparator falls below 1/3 $V_{CC}$, the comparator output triggers the flip–flop so that its output sets low. This turns the capacitor discharge transistor "off" and drives the digital output to the high state. This condition allows the capacitor to charge at an exponential rate which is set by the RC time constant. When the capacitor voltage reaches 2/3 $V_{CC}$, the threshold comparator resets the flip–flop. This action discharges the timing capacitor and returns the digital output to the low state. Once the flip–flop has been triggered by an input signal, it cannot be retriggered until the present timing period has been completed. The time that the output is high is given by the equation $t = 1.1\ R_A\ C$. Various combinations of R and C and their associated times are shown in Figure 16. The trigger pulse width must be less than the timing period.

A reset pin is provided to discharge the capacitor, thus interrupting the timing cycle. As long as the reset pin is low, the capacitor discharge transistor is turned "on" and prevents the capacitor from charging. While the reset voltage is applied the digital output will remain the same. The reset pin should be tied to the supply voltage when not in use.

**Figure 14. Monostable Circuit**

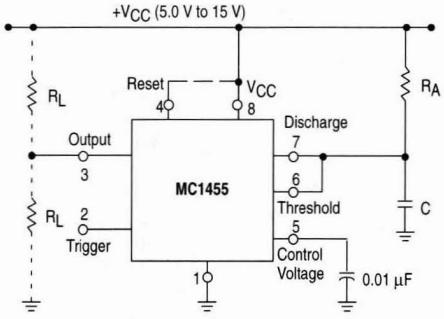
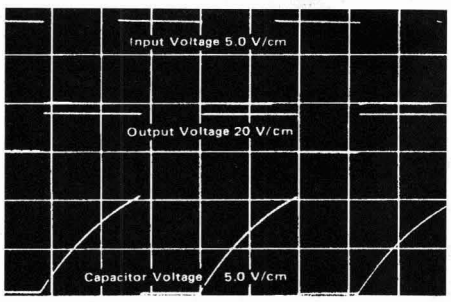


**Figure 15. Monostable Waveforms**




t = 50 μs/cm
($R_A$ = 10 kΩ, C = 0.01 μF, $R_L$ = 1.0 kΩ, $V_{CC}$ = 15 V)

**Figure 16. Time Delay**

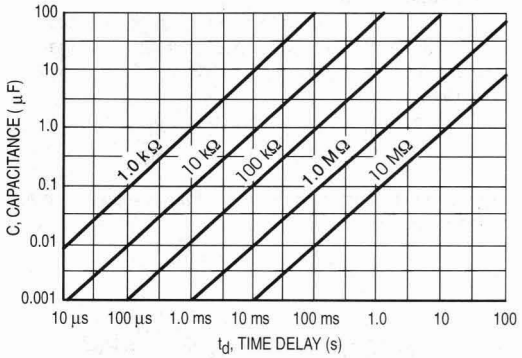



**Figure 17. Astable Circuit**

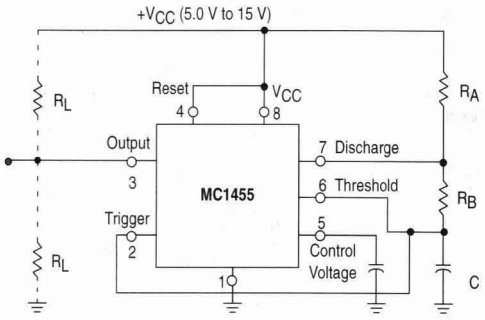
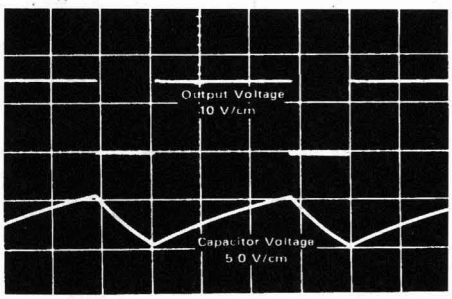



**Figure 18. Astable Waveforms**




t = 20 μs/cm
($R_A$ = 5.1 kΩ, C = 0.01 μF, $R_L$ = 1.0 kΩ; $R_B$ = 3.9 kΩ, $V_{CC}$ = 15 V)

**Astable Mode**

In the astable mode the timer is connected so that it will retrigger itself and cause the capacitor voltage to oscillate between 1/3 $V_{CC}$ and 2/3 $V_{CC}$. See Figure 17.

The external capacitor changes to 2/3 $V_{CC}$ through $R_A$ and $R_B$ and discharges to 1/3 $V_{CC}$ through $R_B$. By varying the ratio of these resistors the duty cycle can be varied. The charge and discharge times are independent of the supply voltage.

The charge time (output high) is given by:

$$t_1 = 0.695\ (R_A + R_B)\ C$$

The discharge time (output low) is given by:

$$t_2 = 0.695\ (R_B)\ C$$

Thus the total period is given by:

$$T = t_1 + t_2 = 0.695\ (R_A + 2R_B)\ C$$

The frequency of oscillation is then: $f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B)\ C}$

and may be easily found as shown in Figure 19.

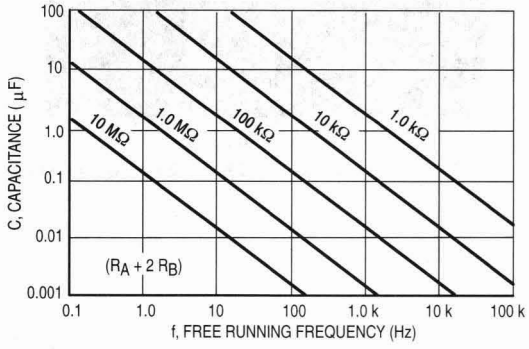
The duty cycle is given by: $DC = \frac{R_B}{R_A + 2R_B}$

To obtain the maximum duty cycle $R_A$ must be as small as possible; but it must also be large enough to limit the discharge current (Pin 7 current) within the maximum rating of the discharge transistor (200 mA).

The minimum value of $R_A$ is given by:

$$R_A \geq \frac{V_{CC}\ (Vdc)}{I7\ (A)} \geq \frac{V_{CC}\ (Vdc)}{0.2}$$

**Figure 19. Free Running Frequency**

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## APPLICATIONS INFORMATION

### Linear Voltage Ramp

In the monostable mode, the resistor can be replaced by a constant current source to provide a linear ramp voltage. The capacitor still charges from 0 $V_{CC}$ to 2/3 $V_{CC}$. The linear ramp time is given by:

$$t = \frac{2}{3}\frac{V_{CC}}{1}, \quad \text{where } I = \frac{V_{CC} - V_B - V_{BE}}{R_E}$$

If $V_B$ is much larger than $V_{BE}$, then t can be made independent of $V_{CC}$.

### Missing Pulse Detector

The timer can be used to produce an output when an input pulse fails to occur within the delay of the timer. To accomplish this, set the time delay to be slightly longer than the time between successive input pulses. The timing cycle is then continuously reset by the input pulse train until a change in frequency or a missing pulse allows completion of the timing cycle, causing a change in the output level.

**Figure 20. Linear Voltage Sweep Circuit**

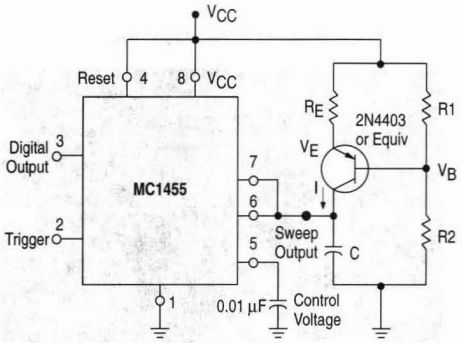



**Figure 21. Missing Pulse Detector**

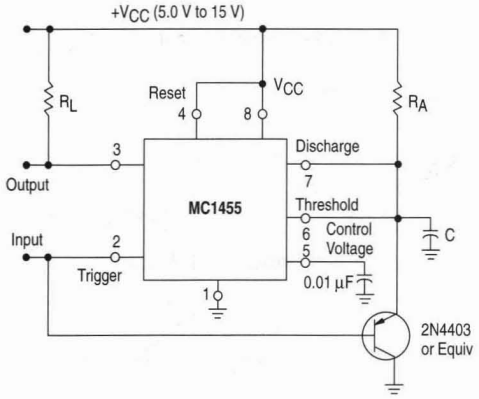
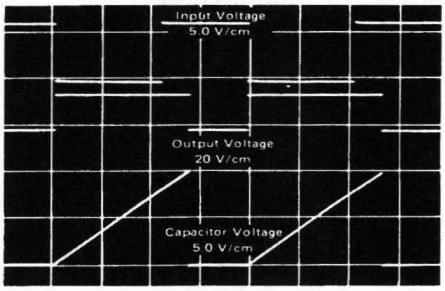


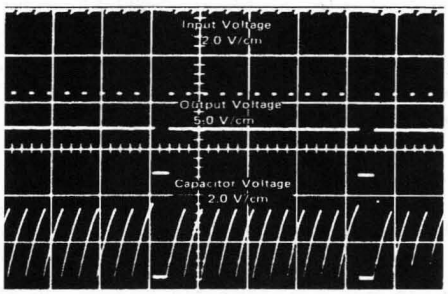

**Figure 22. Linear Voltage Ramp Waveforms**




t = 100 µs/cm

($R_E$ = 10 kΩ, R2 = 100 kΩ, R1 = 39 kΩ, C = 0.01 µF, $V_{CC}$ = 15 V)

**Figure 23. Missing Pulse Detector Waveforms**




t = 500 µs/cm

($R_A$ = 2.0 kΩ, $R_L$ = 1.0 kΩ, C = 0.01 µF, $V_{CC}$ = 15 V)

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### Pulse Width Modulation

If the timer is triggered with a continuous pulse train in the monstable mode of operation, the charge time of the capacitor can be varied by changing the control voltage at Pin 5. In this manner, the output pulse width can be modulated by applying a modulating signal that controls the threshold voltage.

**Figure 24. Pulse Width Modulator**

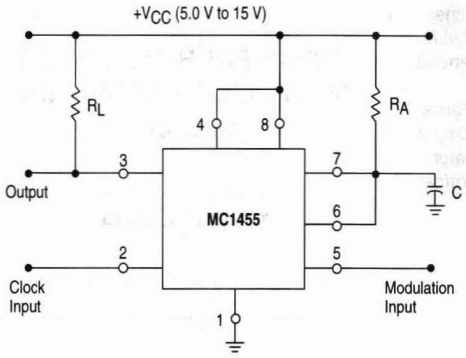
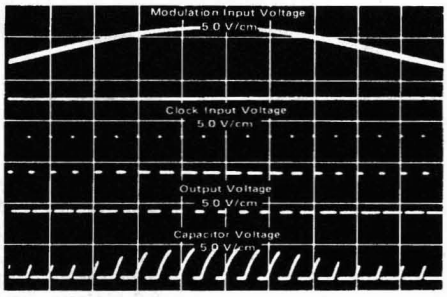



**Figure 25. Pulse Width Modulation Waveforms**

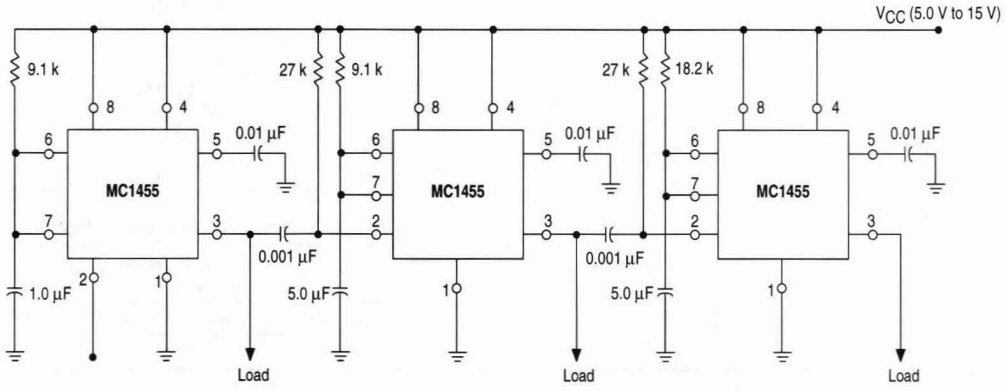



t = 0.5 ms/cm
($R_A$ = 10 kΩ, C = 0.02 μF, $V_{CC}$ = 15 V)

### Test Sequences

Several timers can be connected to drive each other for sequential timing. An example is shown in Figure 26 where the sequence is started by triggering the first timer which runs for 10 ms. The output then switches low momentarily and starts the second timer which runs for 50 ms and so forth.

**Figure 26. Sequential Timer**



MOTOROLA

# MC1494

# Linear Four-Quadrant Multiplier

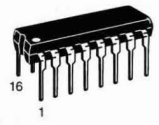
The MC1494 is designed for use where the output voltage is a linear product of two input voltages. Typical applications include: multiply, divide, square root, mean square, phase detector, frequency doubler, balanced modulator/ demodulator, electronic gain control.

The MC1494 is a variable transconductance multiplier with internal level–shift circuitry and voltage regulator. Scale factor, input offsets and output offset are completely adjustable with the use of four external potentiometers. Two complementary regulated voltages are provided to simplify offset adjustment and improve power supply rejection.

- Operates with ±15 V Supplies
- Excellent Linearity: Maximum Error (X or Y) ±1.0 %
- Wide Input Voltage Range: ±10 V
- Adjustable Scale Factor, K (0.1 nominal)
- Single–Ended Output Referenced to Ground
- Simplified Offset Adjust Circuitry
- Frequency Response (3.0 dB Small–Signal): 1.0 MHz
- Power Supply Sensitivity: 30 mV/V typical

**LINEAR FOUR–QUADRANT MULTIPLIER INTEGRATED CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**




**P SUFFIX**
PLASTIC PACKAGE
CASE 648C

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC1494P | $T_A$ = 0° to + 70°C | Plastic DIP |

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**Figure 1. Multiplier Transfer Characteristic**

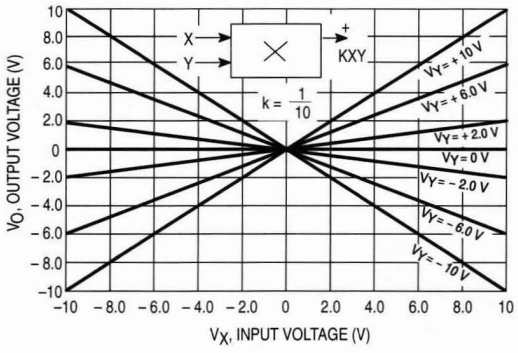
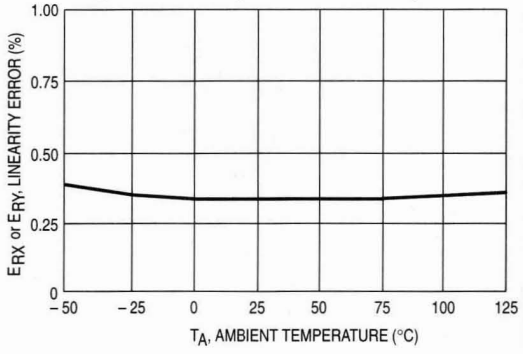



**Figure 2. Linearity Error versus Temperature**



**MAXIMUM RATINGS** ($T_A$ = + 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltages | ± V | ± 18 | Vdc |
| Differential Input Signal | $V_9$–$V_6$<br>$V_{10}$–$V_{13}$ | ±I6 + $I_1R_Y$I<30<br>±I6 + $I_1R_X$I<30 | Vdc |
| Common Mode Input Voltage<br>$V_{CMY}$ = $V_9$ = $V_6$<br>$V_{CMX}$ = $V_{10}$ = $V_{13}$ | <br>$V_{CMY}$<br>$V_{CMX}$ | <br>±11.5<br>±11.5 | Vdc |
| Power Dissipation (Package Limitation)<br>$T_A$ = + 25°C<br>Derate above $T_A$ = + 25°C | <br>$P_D$<br>$1/\theta_{JA}$ | <br>1.25<br>20 | <br>W<br>mW/°C |
| Operating Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** (±V = ±15 V, $T_A$ = + 25°C, R1 = 16 kΩ, $R_X$ = 30 kΩ, $R_Y$ = 62 kΩ, $R_L$ = 47 kΩ, unless otherwise noted.)

| Characteristics | | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Linearity<br>Output error in percent of full scale<br>–10 V <$V_X$ < +10 V ($V_Y$ = ±10 V)<br>–10 V <$V_Y$ < +10 V ($V_X$ = ±10 V)<br>$T_A$ = +25°C<br>$T_A$ = $T_{high}$ or $T_{low}$ (Note 1) | | 3 | $E_{RX}$ or $E_{RY}$ | <br><br><br><br>–<br>– | <br><br><br><br>±0.5<br>– | <br><br><br><br>±1.0<br>±1.3 | % |
| Input<br>Voltage Range ($V_X$ = $V_Y$ = $V_{in}$)<br>Resistance (X or Y Input)<br>Offset Voltage<br><br>Bias Current<br>Offset Current | <br><br><br>(X Input) (Note 1)<br>(Y Input) (Note 1)<br>(X or Y Input)<br>(X or Y Input) | 4, 5, 6 | <br>$V_{in}$<br>$R_{in}$<br>$\|V_{iox}\|$<br>$\|V_{ioy}\|$<br>$I_b$<br>$\|I_{io}\|$ | <br>±10<br>–<br>–<br>–<br>–<br>– | <br>–<br>300<br>0.2<br>0.8<br>1.0<br>50 | <br>–<br>–<br>2.5<br>2.5<br>2.5<br>400 | <br>$V_{pk}$<br>MΩ<br>V<br><br>µA<br>nA |
| Output<br>Voltage Swing Capability<br>Impedance<br>Offset Voltage (Note 1)<br>Offset Current (Note 1) | | 5, 6 | <br>$V_O$<br>$R_O$<br>$\|V_{OO}\|$<br>$\|I_{OO}\|$ | <br>±10<br>–<br>–<br>– | <br>–<br>850<br>1.2<br>25 | <br>–<br>–<br>2.5<br>52 | <br>$V_{pk}$<br>kΩ<br>V<br>µA |
| Temperature Stability (Drift)<br>$T_A$ = $T_{high}$ to $T_{low}$<br>Output Offset (X = 0, Y = 0)<br><br>X Input Offset (Y = 0)<br>Y Input Offset (X = 0)<br>Scale Factor<br>Total DC Accuracy Drift (X = 10, Y = 10) | <br><br>Voltage<br>Current | – | <br><br>$\|TCV_{OO}\|$<br>$\|TCI_{OO}\|$<br>$\|TCV_{iox}\|$<br>$\|TCV_{ioy}\|$<br>\|TCK\|<br>\|TCE\| | <br><br>–<br>–<br>–<br>–<br>–<br>– | <br><br>1.3<br>27<br>0.3<br>1.5<br>0.07<br>0.09 | <br><br>–<br>–<br>–<br>–<br>–<br>– | <br><br>mV/°C<br>nA/°C<br>mV/°C<br><br>%/°C<br> |
| Dynamic Response<br>Small Signal (3.0 dB)<br><br>Power Bandwidth (47 k)<br>3° Relative Phase Shift<br>1% Absolute Error | | 7 | <br>$BW_{3dB}$ (X)<br>$BW_{3dB}$ (Y)<br>$P_{BW}$<br>fϕ<br>fθ | <br>–<br>–<br>–<br>–<br>– | <br>0.8<br>1.0<br>440<br>240<br>30 | <br>–<br>–<br>–<br>–<br>– | <br>MHz<br><br>kHz<br><br> |
| Common Mode<br>Input Swing<br>Gain | <br>(X or Y)<br>(X or Y) | 8 | <br>CMV<br>$A_{CM}$ | <br>±10.5<br>– | <br>–<br>– 65 | <br>–<br>– | <br>$V_{pk}$<br>dB |
| Power Supply<br>Current<br><br>Quiescent Power Dissipation<br>Sensitivity | | 9 | <br>$I_{d+}$<br>$I_{d-}$<br>$P_D$<br>S+<br>S– | <br>–<br>–<br>–<br>–<br>– | <br>6.0<br>6.5<br>185<br>13<br>30 | <br>12<br>12<br>350<br>100<br>200 | <br>mAdc<br><br>mW<br>mV/V<br> |
| Regulated Offset Adjust Voltages<br>Positive/Negative<br>Temperature Coefficient ($V_{R+}$ or $V_{R-}$)<br>Power Supply Sensitivity ($V_{R+}$ or $V_{R-}$) | | 9 | <br>$V_{R+}$, $V_{R-}$<br>$TCV_R$<br>$S_{R+}$, $S_{R-}$ | <br>3.5<br>–<br>– | <br>4.3<br>0.03<br>0.6 | <br>5.0<br>–<br>– | <br>Vdc<br>mV/°C<br>mV/V |

**NOTE:** 1. Offsets can be adjusted to zero with external potentiomers. $T_{High}$ = +70°C, $T_{Low}$ = 0°C

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**Figure 3. Linearity**

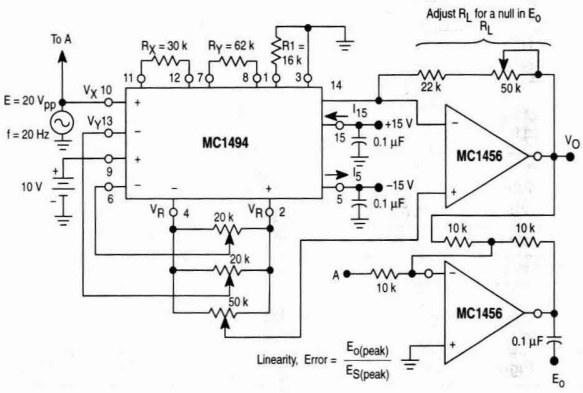


**Figure 4. Input Resistance**

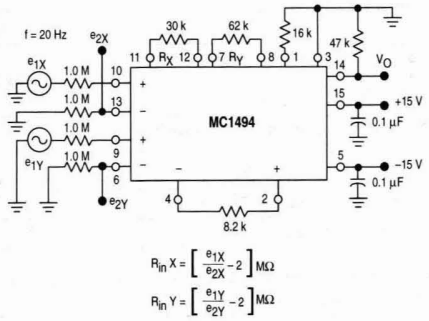


**Figure 5. Offset Voltages, Gain**

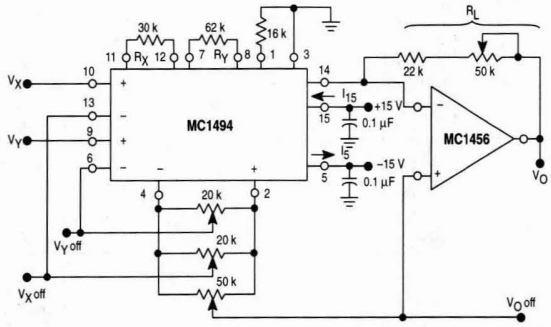


**Figure 6. Input Bias Current/Input Offset Current, Output Resistance**

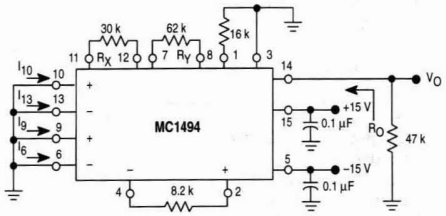


**Figure 7. Frequency Response**

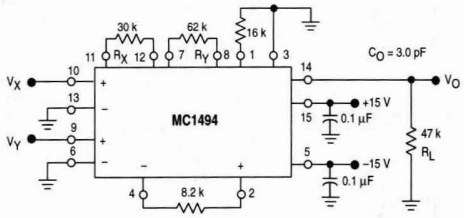


**Figure 8. Common Mode**

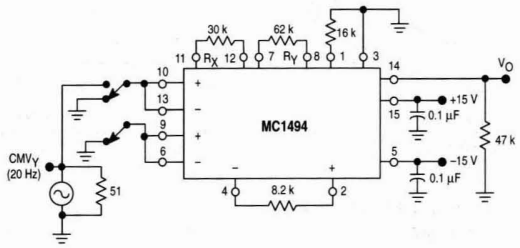


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**Figure 9. Power Supply Sensitivity**

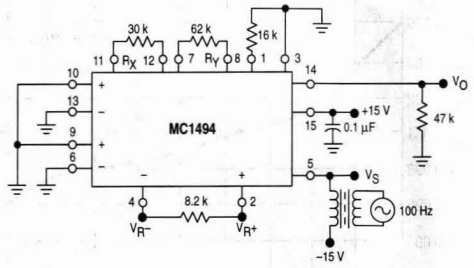


**Figure 10. Burn–In**

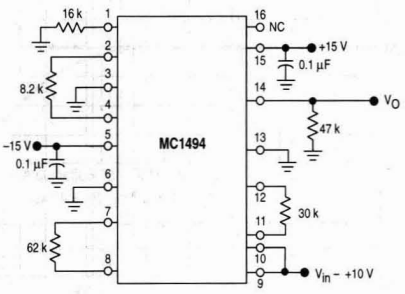


**Figure 11. Frequency Response of Y Input versus Load Resistance**

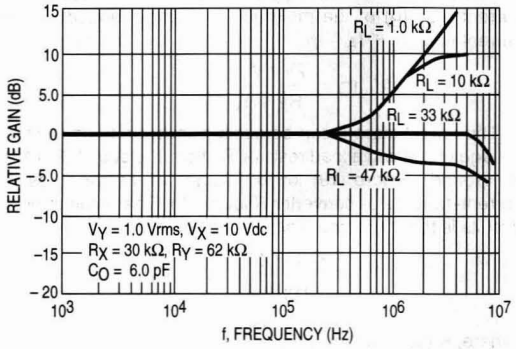


**Figure 12. Frequency Response of X Input versus Load Resistance**

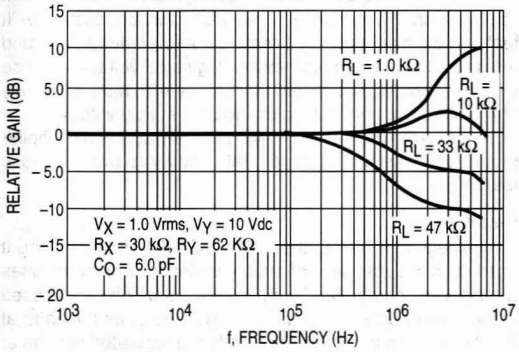


**Figure 13. Linearity versus $R_X$ or $R_Y$ with K = 1**

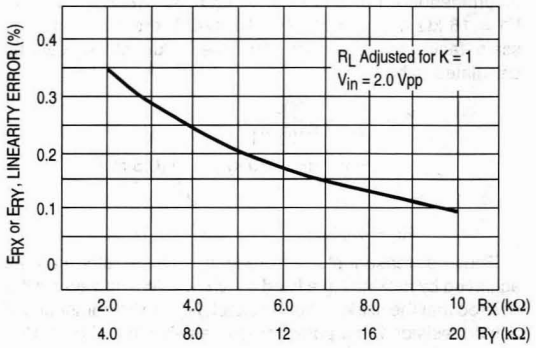


**Figure 14. Linearity versus $R_X$ or $R_Y$ with K = 1/10**

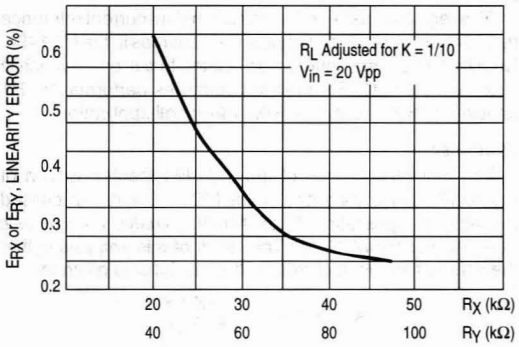


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**Figure 15. Large Signal Voltage versus Frequency**

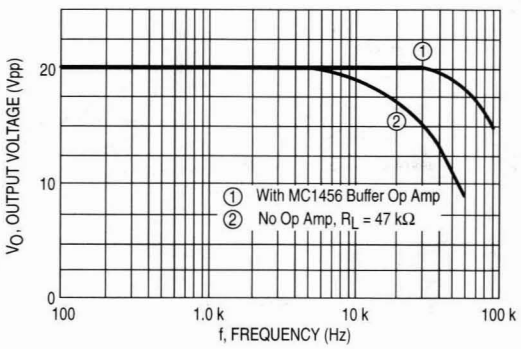
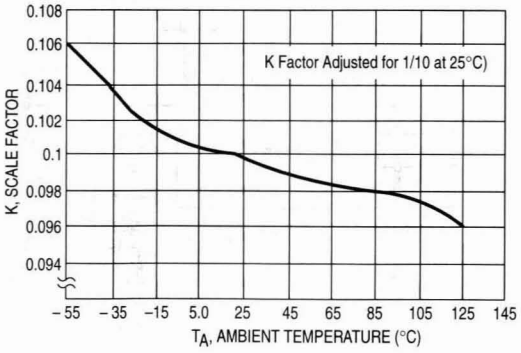



**Figure 16. Scale Factor (K) versus Temperature**




## CIRCUIT DESCRIPTION

### Introduction

The MC1494 is a monolithic, four–quadrant multiplier that operates on the principle of variable transconductance. It features a single–ended current output referenced to ground and provides two complementary regulated voltages for use with the offset adjust circuits to virtually eliminate sensitivity of the offset voltage nulls to changes in supply voltages.

As shown in Figure 17, the MC1494 consists of a multiplier proper and associated peripheral circuitry to provide these features.

### Regulator

The regulator biases the entire MC1494 circuit making it essentially independent of supply variation. It also provides two convenient regulated supply voltages which can be used in the offset adjust circuitry. The regulated output voltage at Pin 2 is approximately + 4.3 V, while the regulated voltage at Pin 4 is approximately – 4.3 V. For optimum temperature stability of these regulated voltages, it is recommended that $|I_2| = |I_4| = 1.0$ mA (equivalent load of 8.6 kΩ). As will be shown later, there will normally be two 20 kΩ potentiometers and one 50 kΩ potentiometer connected between Pins 2 and 4.

The regulator also establishes a constant current reference that controls all of the constant current sources in the MC1494. Note that all current sources are related to current $I_1$ which is determined by R1. For best temperatures performance, R1 should be 16 kΩ so that $I_1 \approx 0.5$ mA for all applications.

### Multiplier

The multiplier section of the MC1494 (center section of Figure 17) is nearly identical to the MC1495 and is discussed in detail in Application Note AN489, *Analysis and Basic Operation of the MC1495*. The result of this analysis is that the differential output current of the multiplier is given by:

$$I_A - I_B = \Delta I \approx \frac{2V_X V_Y}{R_X R_Y I_1}$$

Therefore, the output is proportional to the product of the two input voltages.

### Differential Current Converter

This portion of the circuitry converts the differential output current ($I_A - I_B$) of the multiplier to a single–ended output current ($I_O$); $I_O = I_A - I_B$

$$\text{or } I_O = \frac{2V_X V_Y}{R_X R_Y I_1}$$

The output current can be easily converted to an output voltage by placing a load resistor $R_L$ from the output (Pin 14) to ground (Figure 19) or by using an op amp as a current–to–voltage converter (Figure 18). The result in both circuits is that the output voltage is given by:

$$V_O = \frac{2R_L V_X V_Y}{R_X R_Y I_1} = KV_X V_Y$$

$$\text{where, K (scale factor)} = \frac{2R_L}{R_X R_Y I_1}$$

## DC OPERATION

### Selection of External Components

For low frequency operation the circuit of Figure 18 is recommended. For this circuit, $R_X$ = 30 kΩ, $R_Y$ = 62 kΩ, R1 = 16 kΩ and, hence, $I_1 \approx 0.5$ mA. Therefore, to set the scale factor (K) equal to 1/10, the value of $R_L$ can be calculated to be:

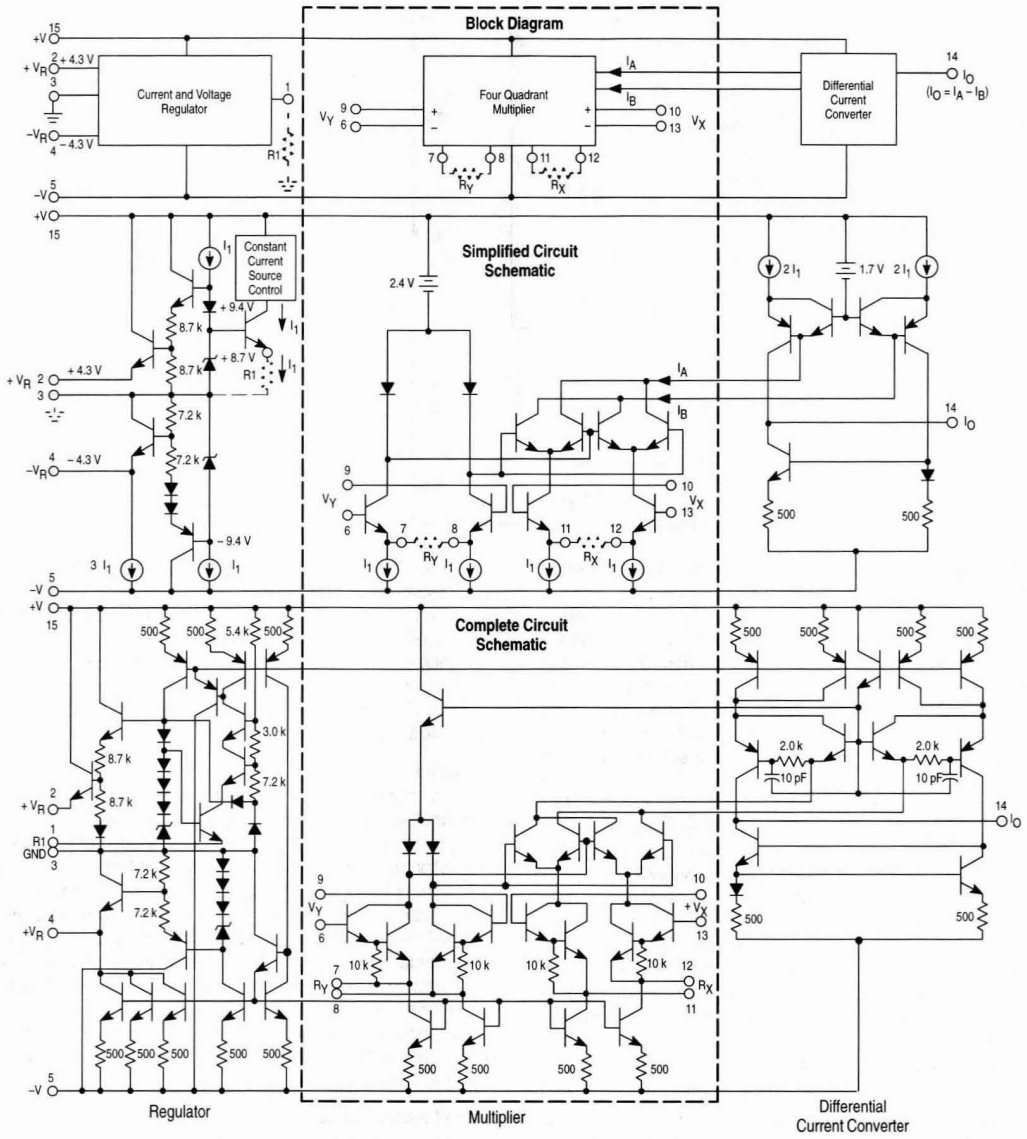
$$K = \frac{1}{10} = \frac{2R_L}{R_X R_Y I_1}$$

$$\text{or } R_L = \frac{R_X R_Y I_1}{(2)(10)} = \frac{(30\text{ k})(62\text{ k})(0.5\text{ mA})}{20}$$

$$R_L = 46.5\text{ k}$$

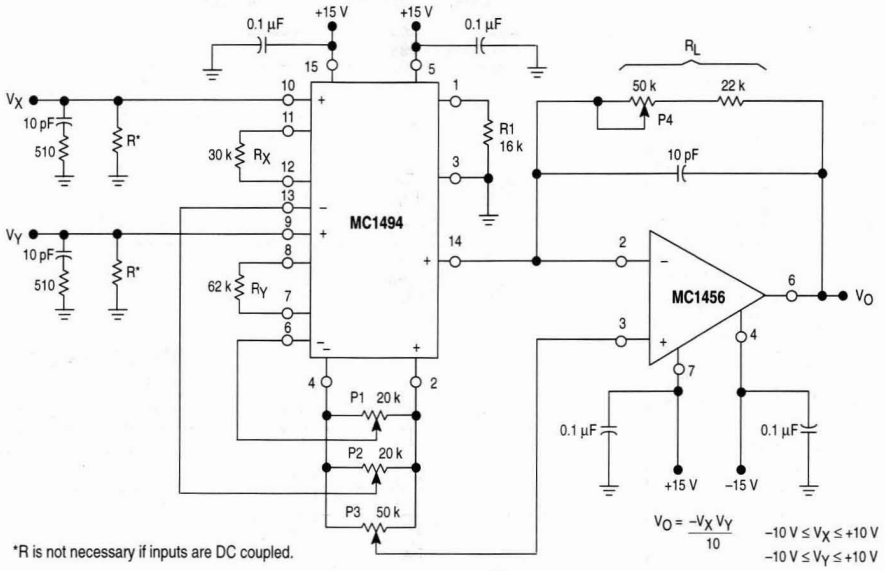
Thus, a reasonable accuracy in scale factor can be achieved by making $R_L$ a fixed 47 kΩ resistor. However, if it is desired that the scale factor be exact, $R_L$ can be comprised of a fixed resistor and a potentiometer as shown in Figure 18.

**Figure 17. Internal Schematic**
(Recommended External Circuitry is Depicted within Dotted Lines)




This device contains 44 active transistors.

**Figure 18. Typical Multiplier Connection**




It should be pointed out that there is nothing magic about setting the scale factor to 1/10. This is merely a convenient factor to use if the $V_X$ and $V_Y$ input voltages are expected to be large, say ±10 V. Obviously with $V_X = V_Y = 10$ V and a scale factor of unity, the device could not hope to provide a 100 V output, so the scale factor is set to 1/10 and provides an output scaled down by a factor of ten. For many applications it may be desirable to set K = 1/2 or K = 1 or even K = 100. This can be accomplished by adjusting $R_X$, $R_Y$ and $R_L$ appropriately.

The selection of $R_L$ is arbitrary and can be chosen after resistors $R_X$ and $R_Y$ are found. Note in Figure 18 that $R_Y$ is 62 kΩ while $R_X$ is 30 kΩ. The reason for this is that the "Y" side of the multiplier exhibits a second order nonlinearity whereas the "X" side exhibits a simple nonlinearity. By making the $R_Y$ resistor approximately twice the value of the $R_X$ resistor, the linearity on both the "X" and "Y" sides are made equal. The selection of the $R_X$ and $R_Y$ resistor values is dependent upon the expected amplitude of $V_X$ and $V_Y$ inputs. To maintain a specified linearity, resistors $R_X$ and $R_Y$ should be selected according to the following equations:

$R_X \geq 3\ V_X$ (max) in kΩ when $V_X$ is in Volts,

$R_Y \geq 6\ V_Y$ (max) in kΩ when $V_Y$ is in Volts.

For example, if the maximum input on the "X" side is ±1.0 V, resistor $R_X$ can be selected to be 3.0 kΩ. If the maximum input on the "Y" side is also ±1.0 V, then resistor $R_Y$ can be selected to be 6.0 kΩ (6.2 kΩ nominal value). If a scale factor of K = 10 is desired, the load resistor is found to be 47 kΩ. In this example, the multiplier provides a gain of 20 dB.

### Operational Amplifier Selection

The operational amplifier connection in Figure 18 is a simple but extremely accurate current–to–voltage converter. The output current of the multiplier flows through the feedback resistor $R_L$ to provide a low impedance output voltage from the op amp. Since the offset current and bias currents of the op amp will cause errors in the output voltage, particularly with temperature, one with very low bias and offset currents is recommended. The MC1456 or MC1741 are excellent choices for this application.

Since the MC1494 is capable of operation at much higher frequencies than the op amp, the frequency characteristics of the circuit in Figure 18 will be primarily dependent upon the operational amplifier.

### Stability

The current–to–voltage converter mode is a most demanding application for an operational amplifier. Loop gain is at its maximum and the feedback resistor in conjunction with stray or input capacitance at the multiplier output adds additional phase shift. It may therefore be necessary to add (particularly in the case of internally compensated op amps) a small feedback capacitor to reduce loop gain at the higher frequencies. A value of 10 pF in parallel with $R_L$ should be adequate to insure stability over production and temperature variations, etc.

An externally compensated op amp might be employed using slightly heavier compensation than that recommended for unity–gain operation.

### Offset Adjustment

The noninverting input of the op amp provides a convenient point to adjust the output offset voltage. By connecting this point to the wiper arm of a potentiometer (P3), the output offset voltage can be adjusted to zero (see Offset and Scale Factor Adjustment Procedure).

The input offset adjustment potentiometers, P1 and P2 will be necessary for most applications where it is desirable to take advantage of the multiplier's excellent linearity characteristics. Depending upon the particular application, some of the potentiometers can be omitted (see Figures 19, 21, 24, 26 and 27).

### Offset and Scale Factor Adjustment Procedure

The adjustment procedure for the circuit of Figure 18 is:

A. X Input Offset
   1. Connect oscillator (1.0 kHz, 5.0 Vpp sinewave) to the "Y" input (Pin 9).
   2. Connect "X" input (Pin 10) to ground.
   3. Adjust X–offset potentiometer, P2 for an AC null at the output.

B. Y Input Offset
   1. Connect oscillator (1.0 kHz, 5.0 Vpp sinewave) to the "X" input (Pin 10).
   2. Connect "Y" input (Pin 9) to ground.
   3. Adjust Y–offset potentiometer, P1 for an AC null at the output.

C. Output Offset
   1. Connect both "X" and "Y" inputs to ground.
   2. Adjust output offset potentiometer, P3 until the output voltage $V_O$ is 0 Vdc.

D. Scale Factor
   1. Apply +10 Vdc to both the "X" and "Y" inputs.
   2. Adjust P4 to achieve –10 V at the output.
   3. Apply –10 Vdc to both "X" and "Y" inputs and check for $V_O$ = –10 V.

E. Repeat steps A through D as necessary.

The ability to accurately adjust the MC1494 is dependent on the offset adjust potentiometers. Potentiometers should be of the "infinite" resolution type rather than wirewound. Fine adjustments in balanced–modulator applications may require two potentiometers to provide "coarse" and "fine" adjustment. Potentiometers should have low temperature coefficients and be free from backlash.

### Temperature Stability

While the MC1494 provides excellent performance in itself, overall performance depends to a large degree on the quality of the external components. Previous discussion shows the direct dependence on $R_X$, $R_Y$ and $R_L$ and indirect dependence on R1 (through $I_1$). *Any circuit subjected to temperature variations should be evaluated with these effects in mind.*

### Bias Currents

The MC1494 multiplier, like most linear ICs, requires a DC bias current into its input terminals. The device cannot be capacitively coupled at the input without regard for this bias current. If inputs $V_X$ and $V_Y$ are able to supply the small bias current (≈ 0.5 μA) resistors R can be omitted (see Figure 18). If the MC1494 is used in an AC mode of operation and capacitive coupling is used the value of resistor R can be any reasonable value up to 100 kΩ. For minimum noise and optimum temperature performance, the value of resistor R should be as low as practical.

### Parasitic Oscillation

When long leads are used on the inputs, oscillation may occur. In this event, an RC parasitic suppression network similar to the ones shown in Figure 18 should be connected directly to each input using short leads. The purpose of the network is to reduce the "Q" of the source–tuned circuits which cause the oscillation.

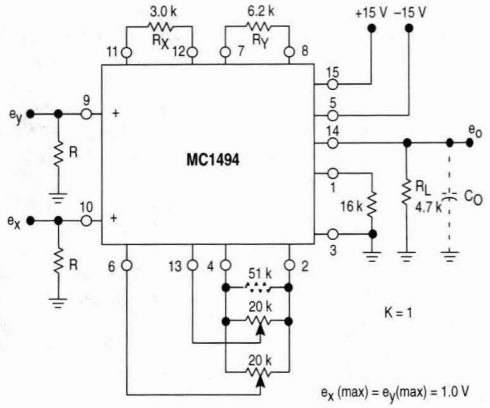
Inability to adjust the circuit to within the specified accuracy may be an indication of oscillation.

## AC OPERATION

### General

For AC operation, such as balanced modulation, frequency doubler, AGC, etc., the op amp will usually be omitted as well as the output offset adjust potentiometer. The output offset adjust potentiometer is omitted since the output will normally be AC coupled and the DC voltage at the output is of no concern providing it is close enough to zero volts that it will not cause clipping in the output waveform. Figure 19 shows a typical AC multiplier circuit with a scale factor K ≈ 1. Again, resistor $R_X$ and $R_Y$ are chosen as outlined in the previous section, with $R_L$ chosen to provide the required scale factor.

**Figure 19. Wideband Multiplier**




The offset voltage then existing at the output will be equal to the offset current times the load resistance. The output offset current of the MC1494 is typically 17 μA and 35 μA maximum. Thus, the maximum output offset would be about 160 mV.

### Bandwidth

The bandwidth of the MC1494 is primarily determined by two factors. First, the dominant pole will be determined by the load resistor and the stray capacitance at the output terminal. For the circuit shown in Figure 19, assuming a total output capacitance ($C_O$) of 10 pF, the 3.0 dB bandwidth would be approximately 3.4 MHz. If the load resistor were 47 kΩ, the bandwidth would be approximately 340 kHz.

Secondly, a "zero" is present in the frequency response characteristic for both the "X" and "Y" inputs which causes the output signal to rise in amplitude at a 6.0 dB/octave slope at frequencies beyond the breakpoint of the "zero". The "zero" is caused by the parasitic and substrate capacitance which is related to resistors $R_X$ and $R_Y$ and the transistors associated with them. The effect of these transmission "zeros" is seen in Figures 11 and 12. The reason for this increase in gain is due to the bypassing of $R_X$ and $R_Y$ at high frequencies. Since the $R_Y$ resistor is approximately twice the value of the $R_X$ resistor, the zero associated with the "Y" input will occur at approximately one octave below the zero associated with "X" input. For $R_X$ = 30 kΩ and $R_Y$ = 62 kΩ, the zeros occur at 1.5 MHz for the "X" input and 700 kHz for the "Y" input. These two measured breakpoints correspond to a shunt capacitance of about 3.5 pF. Thus, for the circuit of

Figure 19, the "X" input zero and "Y" input zero will be at approximately 15 MHz and 7.0 MHz respectively.

It should be noted that the MC1494 multiplies in the time domain, hence, its frequency response is found by means of complex convolution in the frequency (Laplace) domain. This means that if the "X" input does not involve a frequency, it is not necessary to consider the "X" side frequency response in the output product. Likewise, for the "Y" side. Thus, for applications such as a wideband linear AGC amplifier which has a DC voltage as one input, the multiplier frequency response has one zero and one pole. For applications which involve an AC voltage on both the "X" and "Y" side such as a balanced modulator, the product voltage response will have two zeros and one pole, hence, peaking may be present in the output.

From this brief discussion, it is evident that for AC applications; (1) the value of resistors $R_X$, $R_Y$ and $R_L$ should be kept as small as possible to achieve maximum frequency response, and (2) it is possible to select a load resistor $R_L$ such that the dominant pole ($R_L$, $C_O$) cancels the input zero ($R_X$, 3.5 pF or $R_Y$, 3.5 pF) to give a flat amplitude characteristic with frequency. This is shown in Figures 11 and 12. Examination of the frequency characteristics of the "X" and "Y" inputs will demonstrate that for wideband amplifier applications, the best tradeoff with frequency response and gain is achieved by using the "Y" input for the AC signal.

For AC applications requiring bandwidths greater than those specified for the MC1494, two other devices are recommended. For modulator–demodulator applications, the MC1496 may be used up to 100 MHz. For wideband multiplier applications, the MC1495 (using small collector loads and AC coupling) can be used.

### Slew–Rate

The MC1494 multiplier is not slew–rate limited in the ordinary sense that an op amp is. Since all the signals in the multiplier are currents and not voltages, there is no charging and discharging of stray capacitors and thus no limitations beyond the normal device limitataions. However, it should be noted that the quiescent current in the output transistors is 0.5 mA and thus the maximum rate of change of the output voltage is limited by the output load capacitance by the simple equation:

$$\text{Slew Rate } \frac{\Delta V_O}{\Delta T} = \frac{I_O}{C}$$

Thus, if $C_O$ is 10 pF, the maximum slew rate would be:

$$\frac{\Delta V_O}{\Delta T} = \frac{0.5 \times 10^{-3}}{10 \times 10^{-12}} = 50 \text{ V/}\mu\text{s}$$

This can be improved, if necessary, by the addition of an emitter–follower or other type of buffer.

### Phase Vector Error

All multipliers are subject to an error which is known as the phase vector error. This error is a phase error only and does not contribute an amplitude error per se. The phase vector error is best explained by an example. If the "X" input is described in vector notation as;

$$X = A \angle 0°$$

and the "Y" input is described as;

$$Y = B \angle 0°$$

then the output product would be expected to be;

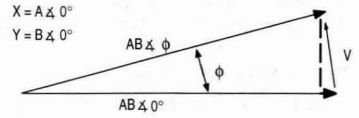
$$V_O = AB \angle 0°$$ (see Figure 20)

However, due to a relative phase shift between the "X" and "Y" channels, the output product will be given by:

$$V_O = AB \angle \phi$$

Notice that the magnitude is correct but the phase angle of the product is in error. The vector (V) associated with this error is the "phase vector error". The startling fact about the phase vector error is that it occurs and accumulates much more rapidly than the amplitude error associated with frequency response. In fact, a relative phase shift of only 0.57° will result in a 1% phase vector error. For most applications, this error is

**Figure 20. Phase Vector Error**




meaningless. If phase of the output product is not important, then neither is the phase vector error. If phase is important, such as in the case of double sideband modulation or demodulation, then a 1% phase vector error will represent a 1% amplitude error a the phase angle of interest.

### Circuit Layout

If wideband operation is desired, careful circuit layout must be observed. Stray capacitance across $R_X$ and $R_Y$ should be avoided to minimize peaking (caused by a zero created by the parallel RC circuit).

## DC APPLICATIONS

### Squaring Circuit

If the two inputs are connected together, the resultant function is squaring:

$$V_O = KV^2$$

where K is the scale factor (see Figure 21).

However, a more careful look at the multiplier's defining equation will provide some useful information. The output voltage, without initial offset adjustments is given by:

$$V_O = K(V_X + V_{iox} - V_{X\ off})\ (V_Y + V_{ioy} - V_{Y\ off}) + V_{OO}$$

(Refer to "Definitions" section for an explanation of terms.)

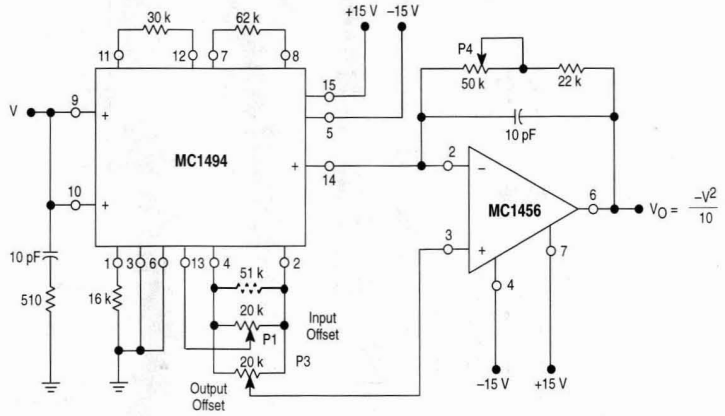
With $V_X = V_Y = V$ (squaring) and defining;

$$\epsilon_x = V_{iox} - V_{x\ (off)}$$
$$\epsilon_y = V_{ioy} - V_{y\ (off)}$$

The output voltage equation becomes:

$$V_O = KV_x^2 + KV_x\ (\epsilon_x + \epsilon_y) + K\epsilon_x\ \epsilon_y + V_{OO}$$

**Figure 21. MC1494 Squaring Circuit**




This shows that all error terms can be eliminated with only three adjustment potentiometers, eliminating one of the input offset adjustments. For instance, if the "X" input offset adjustment is eliminated, $\epsilon_X$ is determined by the internal offset ($V_{iox}$) but $\epsilon_y$ is adjustable to the extent that the ($\epsilon_X + \epsilon_y$) term can be zeroed. Then the output offset adjustment is used to adjust the $V_{OO}$ term and thus zero the remaining error terms. An AC procedure for nulling with three adjustments is:

A. AC Procedure:
   1. Connect oscillator (1.0 kHz, 15 Vpp) to input.
   2. Monitor output at 2.0 kHz with tuned voltmeter and adjust P4 for desired gain ( Be sure to peak response of voltmeter).
   3. Tune voltmeter to 1.0 kHz and adjust P1 for a minimum output voltage.
   4. Ground input and adjust P3 (output offset) for 0 Vdc out.
   5. Repeat steps 1 through 4 as necessary.

B. DC Procedure:
   1. Set $V_X = V_Y = 0$ V and adjust P3 (output offset potentiometer) such that $V_O = 0$ Vdc.
   2. Set $V_X = V_Y = 1.0$ V and adjust P1 (Y input offset potentiometer) such that the output voltage is − 0.100 V.
   3. Set $V_X = V_Y = 10$ Vdc and adjust P4 (load resistor) such that the output voltage is −10 V.
   4. Set $V_X = V_Y = -10$ Vdc and check that $V_O = -10$ V.
   5. Repeat steps 1 through 4 as necessary.

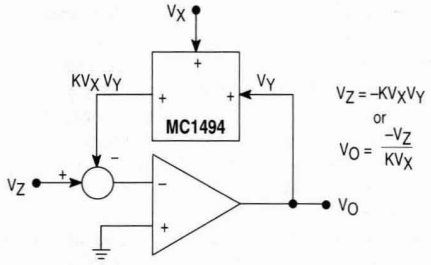
**Divide**

Divide circuits warrant a special discussion as a result of their special problems. Classic feedback theory teaches that if a multiplier is used as a feedback element in an operational amplifier circuit, the divide function results. Figure 22 illustrates the theoretical simplicity of such an approach and a practical realization is shown in Figure 23.

The characteristic "failure" mode of the divide circuit is latch–up. One way it can occur is if $V_X$ is allowed to go negative, or in some cases, if $V_X$ approaches zero.

Figure 22 illustrates why this is so. For $V_X > 0$ the transfer function through the multiplier is noninverting. Its output is fed to the inverting input of the op amp Thus, operation is in the negative feedback mode and the circuit is DC stable.

**Figure 22. Basic Divide Circuit Using Multiplier**

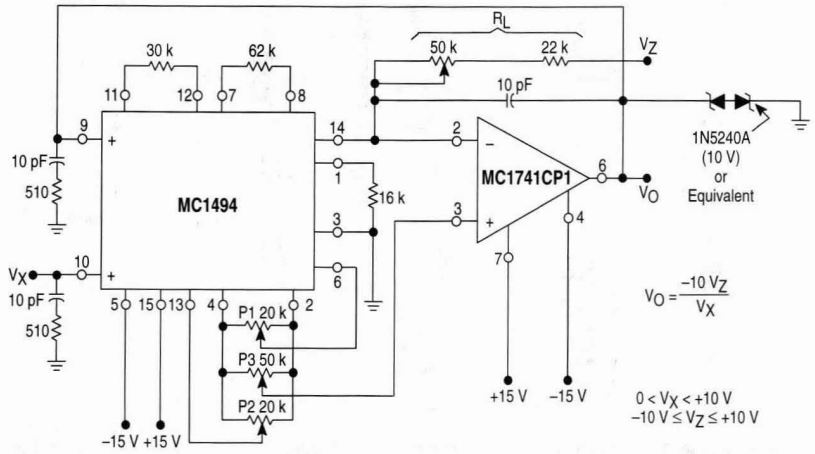



Should $V_X$ change polarity, the transfer function through the multiplier becomes inverting, the amplifier has positive feedback and latch–up results. The problem resulting from $V_X$ being near zero is a result of the transfer through the multiplier being near zero. The op amp is then operating with a very high closed–loop gain and error voltages can thus become effective in causing latch–up.

The other mode of latch–up results from the output voltage of the op amp exceeding the rated common mode input voltage of the multiplier. The input stage of the multiplier becomes saturated, phase reversal results, and the circuit is latched up. The circuit of Figure 23 protects against this happening by clamping the output swing of the op amp to approximately ± 10.7 V. Five percent tolerance, 10 V zeners are used to assure adequate output swing but still limit the output voltage of the op amp from exceeding the common mode input range of the MC1494.

Setting up the divide circuit for reasonably accurate operation is somewhat different from the procedure for the multiplier itself. One approach, however, is to break the feedback loop, null out the multiplier circuit, and then close the loop.

**Figure 23. Practical Divide Circuit**



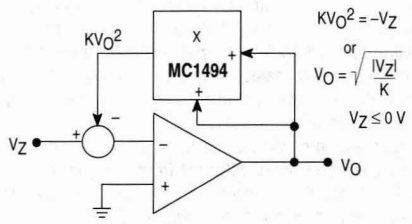

A simpler approach, since it does not involve breaking the loop (thus making it more practical on a production basis), is:

1. Set $V_Z$ = 0 V and adjust the output offset potentiometer (P3) until the output voltage ($V_O$) remains at some (not necessarily zero) constant value as $V_X$ is varied between +1.0 V and +10 V.
2. Maintain $V_Z$ at 0 V, set $V_X$ at +10 V and adjust the Y input offset potentiometer (P1) until $V_O$ = 0 V.
3. With $V_X = V_Z$, adjust the X input offset potentiometer (P2) until the output voltage remains at some (not necessarily −10 V) constant value as $V_Z = V_X$ is varied between +1.0 V and +10 V.
4. Maintain $V_X = V_Z$ and adjust the scale factor potentiometer ($R_L$) until the average value of $V_O$ is −10 V as $V_Z = V_X$ is varied between +1.0 V and +10 V.
5. Repeat steps 1 through 4 as necessary to achieve optimum performance.

Users of the divide circuit should be aware that the accuracy to be expected decreases in direct proportion to the denominator voltage. As a result, if $V_X$ is set to 10 V and 0.5% accuracy is available, then 5% accuracy can be expected when $V_X$ is only 1.0 V.

In accordance with an earlier statement, $V_X$ may have only one polarity (positive) while $V_Z$ may be either polarity.

**Figure 24. Basic Square Root Circuit**




### Square Root

A special case of the divide circuit in which the two inputs to the multiplier are connected together results in the square root function as indicated in Figure 24. This circuit too may suffer from latch–up problems similar to those of the divide circuit. Note that only one polarity of input is allowed and diode clamping (see Figure 25) protects against accidental latch–up.

This circuit too, may be adjusted in the closed–loop mode:

1. Set $V_Z$ = −0.01 Vdc and adjust P3 (output offset) for $V_O$ = 0.316 Vdc.
2. Set $V_Z$ to −0.9 Vdc and adjust P2 ("X" adjust) for $V_O$ = +3.0 Vdc.
3. Set $V_Z$ to −10 Vdc and adjust P4 (gain adjust) for $V_O$ = +10 Vdc.
4. Steps 1 through 3 may be repeated as necessary to achieve desired accuracy.

**NOTE**: Operation near 0 V input may prove very inaccurate, hence, it may not be possible to adjust $V_O$ to zero but rather only to within 100 mV to 400 mV of zero.

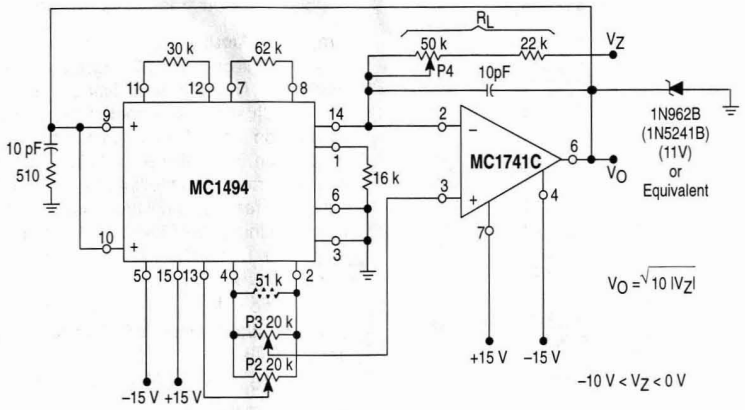
## AC APPLICATIONS

### Wideband Amplifier with Linear AGC

If one input to the MC1494 is a DC voltage and a signal voltage is applied to the other input, the amplitude of the output signal can be controlled in a linear fashion by varying the DC voltage. Hence, the multiplier can function as a DC coupled, wideband amplifier with linear AGC control.

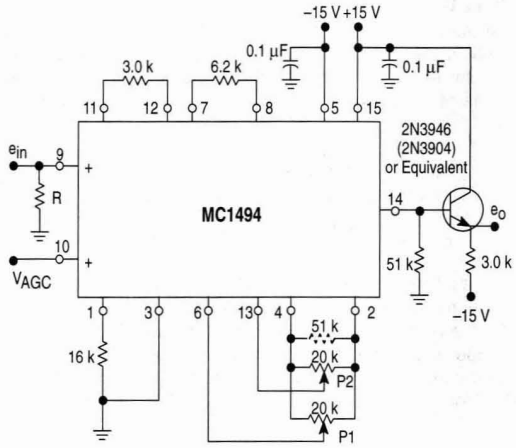
In addition to the advantage of linear AGC control, the multiplier has three other distinct advantages over most other types of AGC systems. First, the AGC dynamic range is theoretically infinite. This stems from the basic fact that with 0 Vdc applied to the AGC, the output will be zero regardless of the input. In practice, the dynamic range is limited by the ability to adjust the input offset adjust potentiometers. By using cermet multi–turn potentiometers, a dynamic range of 80 dB can be obtained. The second advantage of the multiplier is that variation of the AGC voltage has no effect on the signal handling capability of the signal port, nor does it alter the input impedance of the signal port. This feature is particularly important in AGC systems which are phase sensitive. A third advantage of the multiplier is that the output voltage swing capability and output impedance are unchanged with variations in AGC voltage.

**Figure 25. Square Root Circuit**




The circuit of Figure 26 demonstrates the linear AGC amplifier. The amplifier can handle 1.0 Vrms and exhibits a gain of approximately 20 dB. It is AGC'd through a 60 dB dynamic range with the application of an AGC voltage from 0 Vdc to 1.0 Vdc. The bandwidth of the amplifier is determined by the load resistor and output stray capacitance. For this reason, an emitter–follower buffer has been added to extend the bandwidth in excess of 1.0 MHz.

**Figure 26. Wideband Amplifier with Linear AGC**




**Balanced Modulator**

When two–time variant signals are used as inputs, the resulting output is suppressed–carrier double–sideband modulation. In terms of sinusoidal inputs, this can be seen in the following equation:

$$V_O = K(e_1 \cos\omega_m t)\,(e_2 \cos\omega_c t)$$

where $\omega_m$ is the modulation frequency and $\omega_c$ is the carrier frequency. This equation can be expanded to show the suppressed carrier or balanced modulation:

$$V_O = \frac{Ke_1e_2}{2}\,[\cos(\omega_c+\omega_m)\,t + \cos(\omega_c \pm\omega_m)t]$$

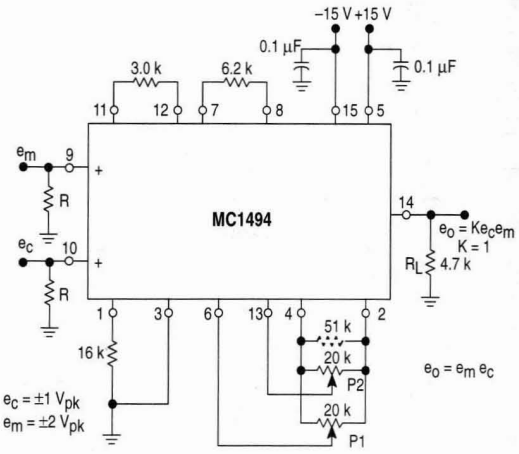
Unlike many modulation schemes, which are nonlinear in nature, the modulation which takes place when using the MC1494 is linear. This means that for two sinusoidal inputs, the output will contain only two frequencies, the sum and difference, as seen in the above equation. There will be no spectrum centered about the second harmonic of the carrier, or any multiple of the carrier. For this reason, the filter requirements of a modulation system are reduced to the minimum. Figure 27 shows the MC1494 configuration to perform this function.

Notice that the resistor values for $R_X$, $R_Y$ and $R_L$ have been modified. This has been done primarily to increase the bandwidth by lowering the output impedance of the MC1494 and then lowering $R_X$ and $R_Y$ to achieve a gain of 1. The $e_c$ can be as large as 1.0 V peak and $e_m$ as high as 2.0 V peak. No output offset adjust is employed since we are interested only in the AC output components.

The input reisstors (R) are used to supply bias current to the multiplier inputs as well as provide matching input impedance. The output frequency range of this configuration is determined by the 4.7 kΩ output impedance and capacitive loading. Assuming a 6.0 pF load, the small–signal bandwidth is 5.5 MHz.

The circuit of Figure 27 will provide at typical carrier rejection of ≥ 70 dB from 10 kHz to 1.5 MHz.

**Figure 27. Balanced Modulator**




The adjustment procedure for this circuit is quite simple.

1. Place the carrier signal at Pin 10. With no signal applied to Pin 9, adjust potentiometer P1 such that an AC null is obtained at the output.
2. Place a modulation signal at Pin 9. With no signal applied to Pin 10, adjust potentiometer P2 such that an AC null is obtained at the output.

Again, the ability to make careful adjustment of these offsets will be a function of the type of potentiometers used for P1 and P2. Multiple turn cermet type potentiometers are recommended.

**Frequency Doubler**

If for Figure 27 both inputs are identical:

$$e_m = e_c = E\cos\omega t$$

then the output is given by,

$$e_o = e_m e_c = E^2\cos^2\omega t$$

which reduces to,

$$e_o = \frac{E^2}{2}(1 + \cos 2\omega t)$$

This equation states that the output will consist of a DC term equal to one half the peak voltage squared and the second harmonic of the input frequency. Thus, the circuit acts as a frequency doubler. Two facts about this circuit are worthy of note. First, the second harmonic of the input frequency is the only frequency appearing at the output. The fundamental does not appear. Second, if the input is sinusoidal, the output will be sinusoidal and requires *no* filtering.

The circuit of Figure 27 can be used as a frequency doubler with input frequencies in excess of 2.0 MHz.

**Amplitude Modulator**

The circuit of Figure 27 is also easily used as an amplitude modulator. This is accomplished by simply varying the input offset adjust potentiometer (P1) associated with the mudulation input. This procedure places a DC offset on the modulation input of the multiplier such that the carrier still passes through the multiplier when the modulating signal is zero. The result is amplitude modulation. This is easily seen by examining the basic mathematical expression for amplitude modulation given below. For the case under discussion, with K = 1,

$$e_o = (E + E_m\cos\omega_m t)(E_c\cos\omega_c t)$$

where E is the DC input offset adjust voltage. This expression can be written as:

$$e_o = E_o[1 + M\cos\omega_c t]\cos\omega_c t$$

where, $E_o = EE_c$

and, $M = \frac{E_m}{E}$ = modulation index.

This is the standard equation for amplitude modulation. From this, it is easy to see that 100% modulation can be achieved by adjusting the input offset adjust voltage to be exactly equal to the peak value of the modulation ($E_m$). This is done by observing the output waveform and adjusting the input offset potentiometer (P1) until the output exhibits the familiar amplitude modulation waveform.

**Phase Detector**

If the circuit of Figure 27 has as its inputs two signals of identical frequency, but having a relative phase shift, the output will be a DC signal which is directly proportional to the cosine of phase difference as well as the double frequency term.

$$e_c = E_c\cos\omega_c t$$
$$e_m = E_m\cos(\omega_c t + \phi)$$
$$e_o = e_c e_m = E_c E_m\cos\omega_c t\cos(\omega_c t + \phi)$$

$$\text{or, } e_o = \frac{E_c E_m}{2}[\cos\phi + \cos(2\omega_c t + \phi)]$$

The addition of a simple low pass filter to the output (which eliminates the second cosine term) and return of $R_L$ to an offset adjustment potentiometer will result in a DC output voltage which is proportional to the cosine of the phase difference. Hence, the circuit functions as a synchronous detector.

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## DEFINITION OF SPECIFICATIONS

Because of the unique nature of a multiplier, i.e., two inputs and one output, operating specifications are difficult to define and interpret. Indeed the same specification may be defined in several completely different ways depending upon which manufacturer is doing the defining. In order to clear up some of the mystery, the following definitions and examples are presented.

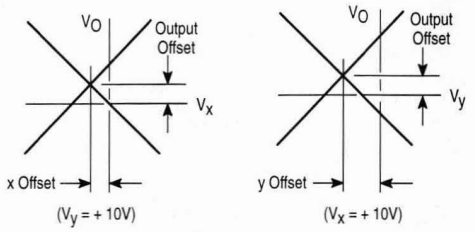
**Multiplier Transfer Function –** The output of the multiplier may be expressed by the following equation:

$$V_O = K[V_X \pm V_{iox} - V_{x(off)}] [V_y \pm V_{ioy} - V_{y(off)}] \pm V_{OO} \quad (1)$$

where, K = scale factor
$V_X$ = "x" input voltage
$V_y$ = "y" input voltage
$V_{iox}$ = "x" input offset voltage
$V_{ioy}$ = "y" input offset voltage
$V_{x(off)}$ = "x" input offset adjust voltage
$V_{y(off)}$ = "y" input offset adjust voltage
$V_{OO}$ = output offset voltage

The voltage transfer characteristic below indicates x, y and output offset voltages.

**Figure 28. Offset Voltages**




**Linearity –** Linearity is defined to be the maximum deviation of output voltage from a straight line transfer function. It is expressed as a percentage of full–scale output and is measured for $V_X$ and $V_y$ separately, either using an X–Y plotter (and checking the deviation from a straight line) or by using the method shown in Figure 3. The latter method nulls the output signal with the input signal, resulting in distortion components proportional to the linearity.

Example: 0.35% linearity means

$$V_O = \frac{V_X V_y}{10} \pm (0.0035)(10\ V)$$

**Input Offset Voltage –** The input offset voltage is defined from Equation (1). It is measured for $V_X$ and $V_y$ separately and is defined to be that DC input offset adjust voltage (x or y) that will result in minimum AC output when AC (5.0 Vpp, 1.0 kHz) is applied to the other input (y or x, respectively). From Equation (1) we have:

$$V_O(AC) = K [0 \pm V_{iox} - V_{x(off)}] [\sin\omega t]$$

adjust $V_{x(off)}$ so that $[\pm V_{iox} - V_{x(off)}] = 0$.

**Output Offset Current and Voltage –** Output offset current ($I_{OO}$) is the DC current flowing in the output lead when $V_X = V_y = 0$ and X and Y offset voltages are adjusted to zero.

Output offset voltage ($V_{OO}$) is:

$$V_{OO} = I_{OO} R_L$$

where $R_L$ is the load resistance.

**NOTE:** Output offset voltage is defined by many manufacturers with all inputs at zero but without adjusting X and Y offset voltages to zero. Thus, it includes input offset terms, an output offset term and a scale factor term.

**Scale Factor –** Scale factor is the K term in Equation (1). It determines the gain of the multiplier and is expressed approximately by the following equation.

$$K = \frac{2R_L}{R_X R_y I_1}, \text{ where } R_X \text{ and } R_y >> \frac{kT}{qI_1}$$

and $I_1$ is the current out of Pin 1.

**Total DC Accuracy –** The total DC accuracy of a multiplier is defined as error in multiplier output with DC (± 10 Vdc) applied to both inputs. It is expressed as a percent of full scale. Accuracy is not specified for the MC1494 because error terms can be nulled by the user.

**Temperature Stability (Drift) –** Each term defined above will have a finite drift with temperature. The temperature specifications are obtained by readjusting the multiplier offsets and scale factor at each new temperature (see previous definitions and the adjustment procedure) and noting the change.

Assume inputs are grounded and initial offset voltages have been adjusted to zero. Then output voltage drift is given by:

$$\Delta V_O = \pm [K \pm K (TCK) (\Delta T)] [(TCV_{iox}) (\Delta T)] [(TCV_{ioy}) (\Delta T)] \pm (TCV_{OO}) (\Delta T)$$

**Total DC Accuracy Drift –** This is the temperature drift in output voltage with 10 V applied to each input. The output is adjusted to 10 V at $T_A = +25°C$. Assuming initial offset voltages have been adjusted to zero at $T_A = +25°C$, then:

$$V_O = [K \pm K (TCK) (\Delta T)] [10 \pm (TCV_{iox}) (\Delta T)] [10 \pm (TCV_{ioy}) (\Delta T)] \pm (TCV_{OO}) (\Delta T)$$

**Power Supply Rejection –** Variation in power supply voltages will cause undesired variation of the output voltage. It is measured by superimposing a 1.0 V, 100 Hz signal on each supply (±15 V) with each input grounded. The resulting change in the output is expressed in mV/V.

**Output Voltage Swing –** Output voltage swing capability is the maximum output voltage swing (without clipping) into a resistive load. (Note, output offset is adjusted to zero).

If an op amp is used, the multiplier output becomes a virtual ground – the swing is then determined by the scale factor and the op amp selected.

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MOTOROLA

# MC1495

# Wideband Linear Four-Quadrant Multiplier

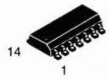
The MC1495 is designed for use where the output is a linear product of two input voltages. Maximum versatility is assured by allowing the user to select the level shift method. Typical applications include: multiply, divide*, square root*, mean square*, phase detector, frequency doubler, balanced modulator/demodulator, and electronic gain control.

- Wide Bandwidth
- Excellent Linearity:
  2% max Error on X Input, 4% max Error on Y Input Over Temperature
  1% max Error on X Input, 2% max Error on Y Input at + 25°C
- Adjustable Scale Factor, K
- Excellent Temperature Stability
- Wide Input Voltage Range: ± 10 V
- ±15 V Operation

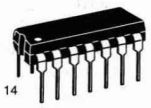
*When used with an operational amplifier.

**LINEAR FOUR-QUADRANT MULTIPLIER**

**SEMICONDUCTOR TECHNICAL DATA**




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO-14)




**P SUFFIX**
PLASTIC PACKAGE
CASE 646

**MAXIMUM RATINGS** ($T_A$ = + 25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Applied Voltage ($V_2$–$V_1$, $V_{14}$–$V_1$, $V_1$–$V_9$, $V_1$–$V_{12}$, $V_1$–$V_4$, $V_1$–$V_8$, $V_{12}$–$V_7$, $V_9$–$V_7$, $V_8$–$V_7$, $V_4$–$V_7$) | ΔV | 30 | Vdc |
| Differential Input Signal | $V_{12}$–$V_9$<br>$V_4$–$V_8$ | ± (6+$I_{13}$ $R_X$)<br>± (6+$I_3$ $R_Y$) | Vdc |
| Maximum Bias Current | $I_3$<br>$I_{13}$ | 10<br>10 | mA |
| Operating Temperature Range<br>MC1495<br>MC1495B | $T_A$ | <br>0 to +70<br>– 40 to +125 | °C |
| Storage Temperature Range | $T_{stg}$ | – 65 to +150 | °C |

**ORDERING INFORMATION**

| Device | Tested Operating Temperature Range | Package |
|---|---|---|
| MC1495D | $T_A$ = 0° to + 70°C | SO–14 |
| MC1495P | | Plastic DIP |
| MC1495BP | $T_A$ = – 40° to +125°C | Plastic DIP |

**ELECTRICAL CHARACTERISTICS** (+V = + 32 V , –V = –15 V, $T_A$ = + 25°C, $I_3 = I_{13}$ = 1.0 mA, $R_X = R_Y$ = 15 kΩ, $R_L$ = 11 kΩ, unless otherwise noted.)

| Characteristics | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Linearity (Output Error in percent of full scale) | 5 | | | | | % |
| $T_A$ = + 25°C | | | | | | |
| –10 < $V_X$ < +10 ($V_Y$ = ±10 V) | | $E_{RX}$ | – | ±1.0 | ±1.0 | |
| –10 < $V_Y$ < +10 ($V_X$ = ±10 V) | | $E_{RY}$ | – | ± 2.0 | ± 2.0 | |
| $T_A = T_{Low}$ to $T_{High}$ | | | | | | |
| –10 < $V_X$ < +10 ($V_Y$ = ±10 V) | | $E_{RX}$ | – | ±1.5 | ± 2.0 | |
| –10 < $V_Y$ < +10 ($V_X$ = ±10 V) | | $E_{RY}$ | – | ± 3.0 | ± 4.0 | |
| Square Mode Error (Accuracy in percent of full scale after Offset and Scale Factor adjustment) | 5 | $E_{SQ}$ | | | | % |
| $T_A$ = + 25°C | | | – | ± 0.75 | – | |
| $T_A = T_{Low}$ to $T_{High}$ | | | – | ±1.0 | – | |
| Scale Factor (Adjustable) $\left(K = \frac{2R_L}{I_3 R_X R_Y}\right)$ | – | K | – | 0.1 | – | |
| Input Resistance (f = 20 Hz) | 7 | $R_{inX}$ | – | 30 | – | MΩ |
| | | $R_{inY}$ | – | 20 | – | |
| Differential Output Resistance (f = 20 Hz) | 8 | $R_O$ | – | 300 | – | kΩ |
| Input Bias Current | 6 | | | | | µA |
| $I_{bx} = \frac{(I_9 + I_{12})}{2}$, $I_{by} = \frac{(I_4 + I_8)}{2}$ $T_A$ = + 25°C | | $I_{bx}$, $I_{by}$ | – | 2.0 | 8.0 | |
| $T_A = T_{Low}$ to $T_{High}$ | | | – | 2.0 | 12 | |
| Input Offset Current | 6 | | | | | µA |
| $\lvert I_9 - I_{12}\rvert$ $T_A$ = + 25°C | | $\lvert I_{iox}\rvert$, $\lvert I_{ioy}\rvert$ | – | 0.4 | 1.0 | |
| $\lvert I_4 - I_8\rvert$ $T_A = T_{Low}$ to $T_{High}$ | | | – | 0.4 | 2.0 | |
| Average Temperature Coefficient of Input Offset Current | 6 | $\lvert TC_{Iio}\rvert$ | | | | nA/°C |
| $T_A = T_{Low}$ to $T_{High}$ | | | – | 2.5 | – | |
| Output Offset Current $T_A$ = + 25°C | 6 | $\lvert I_{OO}\rvert$ | | 10 | 50 | µA |
| $\lvert I_{14} - I_2\rvert$ $T_A = T_{Low}$ to $T_{High}$ | | | – | 20 | 100 | |
| Average Temperature Coefficient of Output Offset Current | 6 | $\lvert TC_{IOO}\rvert$ | | | | nA/°C |
| $T_A = T_{Low}$ to $T_{High}$ | | | – | 20 | – | |
| Frequency Response | 9,10 | | | | | |
| 3.0 dB Bandwidth, $R_L$ = 11 kΩ | | $BW_{(3dB)}$ | – | 3.0 | – | MHz |
| 3.0 dB Bandwidth, $R_L$ = 50 Ω (Transconductance Bandwidth) | | $T_{BW(3dB)}$ | – | 80 | – | MHz |
| 3° Relative Phase Shift Between $V_X$ and $V_Y$ | | fϕ | – | 750 | – | kHz |
| 1% Absolute Error Due to Input-Output Phase Shift | | fθ | – | 30 | – | kHz |
| Common Mode Input Swing | 11 | CMV | | | | Vdc |
| (Either Input) | | | ±10.5 | ±12 | – | |
| Common Mode Gain $T_A$ = + 25°C | 11 | $A_{CM}$ | – 50 | – 60 | – | dB |
| (Either Input) $T_A = T_{Low}$ to $T_{High}$ | | | – 40 | – 50 | – | |
| Common Mode Quiescent | 12 | $V_{O1}$ | – | 21 | – | Vdc |
| Output Voltage | | $V_{O2}$ | – | 21 | – | |
| Differential Output Voltage Swing Capability | 9 | $V_O$ | – | ±14 | – | $V_{pk}$ |
| Power Supply Sensitivity | 12 | $S^+$ | – | 5.0 | – | mV/V |
| | | $S^-$ | – | 10 | – | |
| Power Supply Current | 12 | $I_7$ | – | 6.0 | 7.0 | mA |
| DC Power Dissipation | 12 | $P_D$ | – | 135 | 170 | mW |

**NOTES:** 1. $T_{High}$ = +70°C for MC1495 = +125°C for MC1495B $T_{Low}$ = 0°C for MC1495 = – 40°C for MC1495B

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**Figure 1. Multiplier Transfer Characteristic**

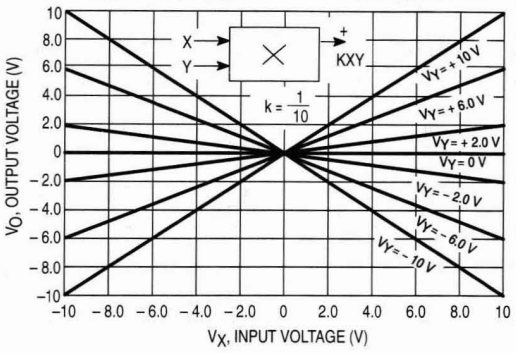



**Figure 2. Transconductance Bandwidth**

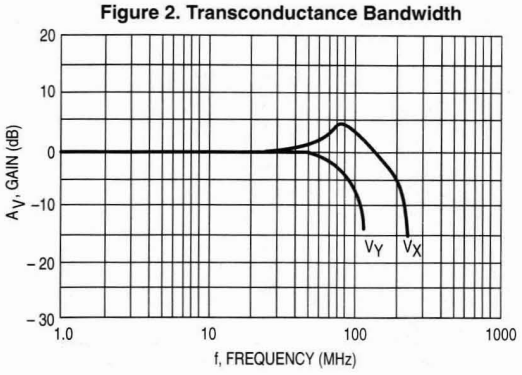
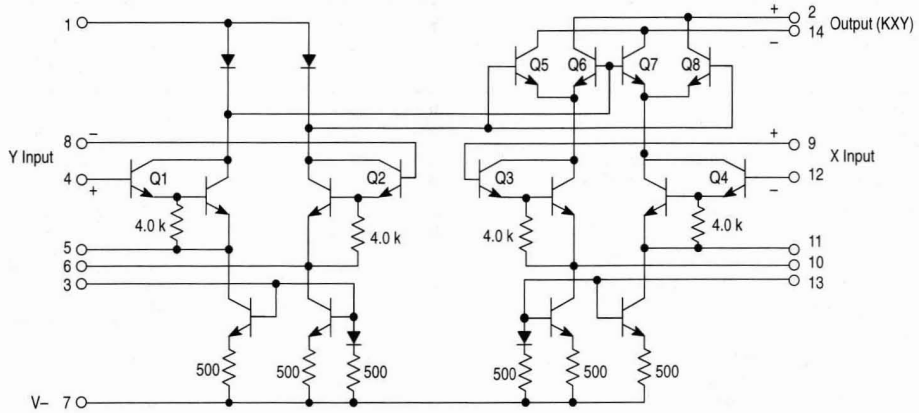
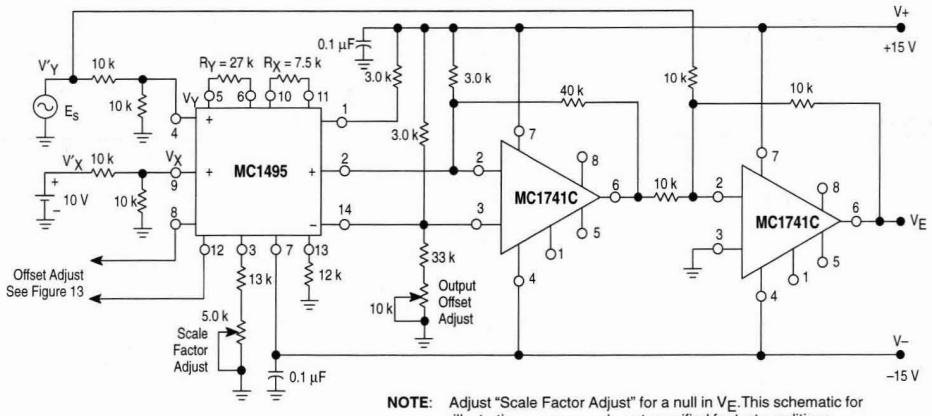



**Figure 3. Circuit Schematic**




This device contains 16 active transistors.

**Figure 4. Linearity (Using Null Technique)**




**NOTE:** Adjust "Scale Factor Adjust" for a null in $V_E$. This schematic for illustrative purposes only, not specified for test conditions.

**Figure 5. Linearity (Using X-Y Plotter Technique)**

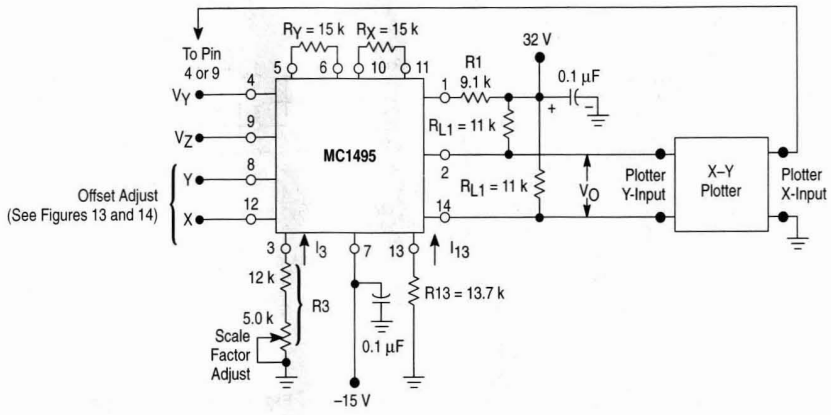



**Figure 6. Input and Output Current**

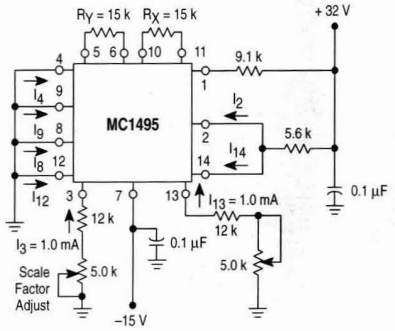



**Figure 7. Input Resistance**

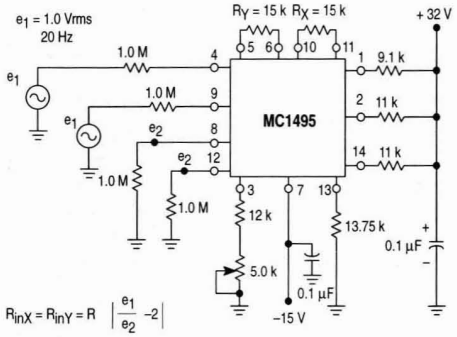



**Figure 8. Output Resistance**

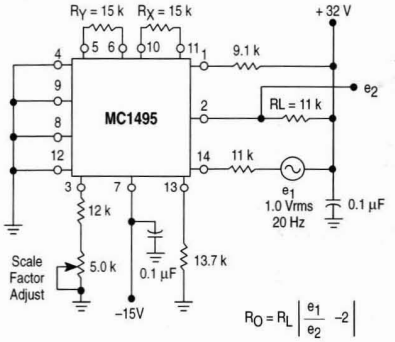



**Figure 9. Bandwidth ($R_L$ = 11 kΩ)**

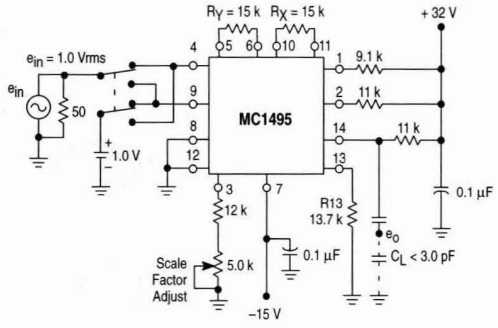



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**Figure 10. Bandwidth ($R_L$ = 50 Ω)**

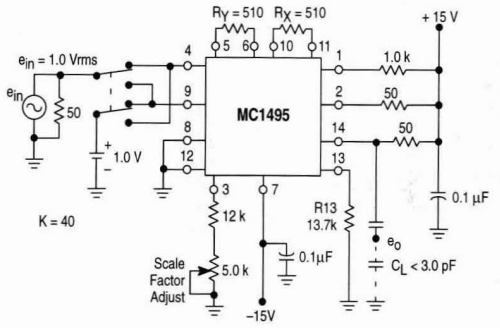



**Figure 11. Common Mode Gain and Common Mode Input Swing**

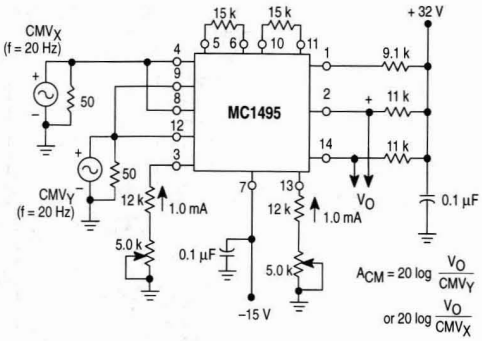



**Figure 12. Power Supply Sensitivity**

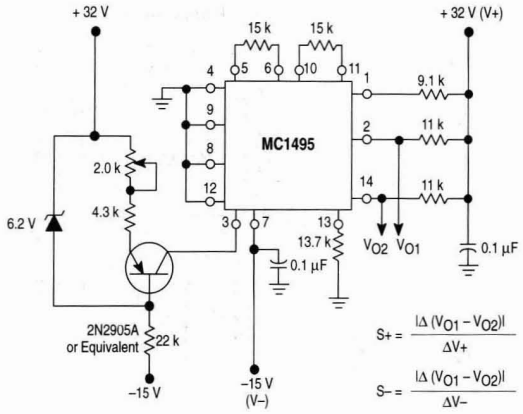
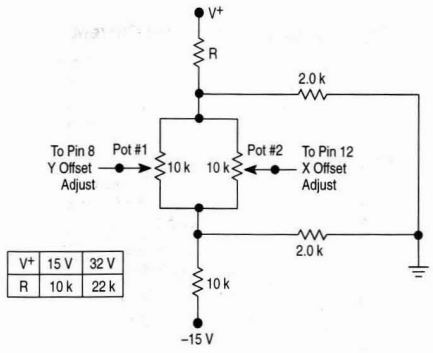
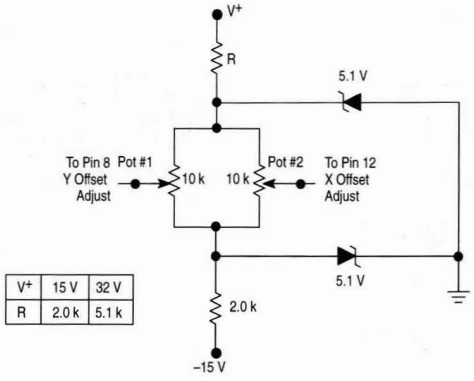



**Figure 13. Offset Adjust Circuit**




| V+ | 15 V | 32 V |
|---|---|---|
| R | 10 k | 22 k |

**Figure 14. Offset Adjust Circuit (Alternate)**




| V+ | 15 V | 32 V |
|---|---|---|
| R | 2.0 k | 5.1 k |

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**Figure 15. Linearity versus Temperature**

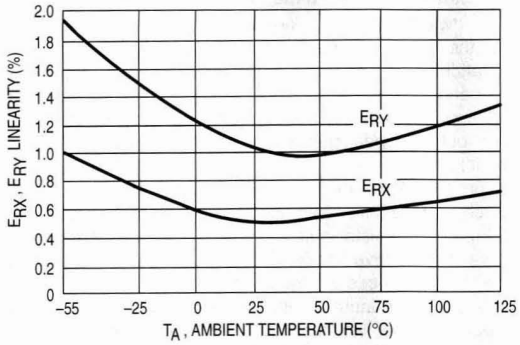



**Figure 16. Scale Factor versus Temperature**

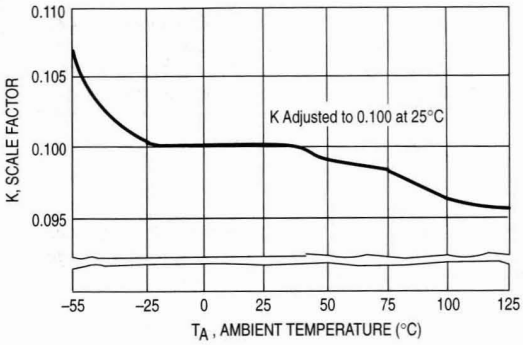



**Figure 17. Error Contributed by Input Differential Amplifier**

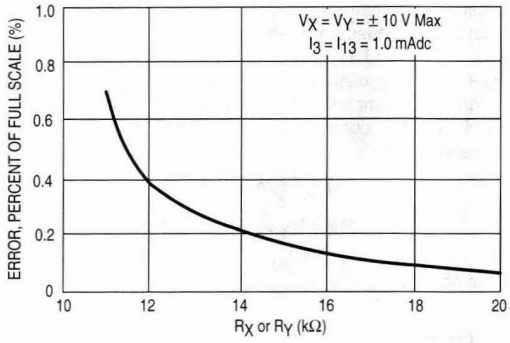



**Figure 18. Error Contributed by Input Differential Amplifier**

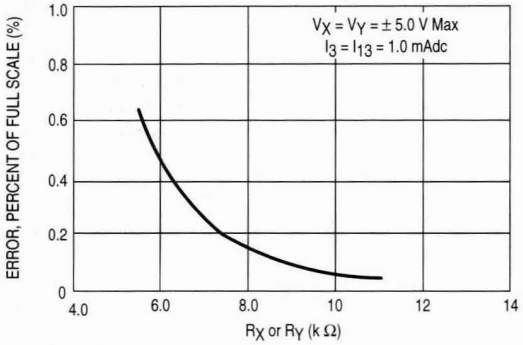
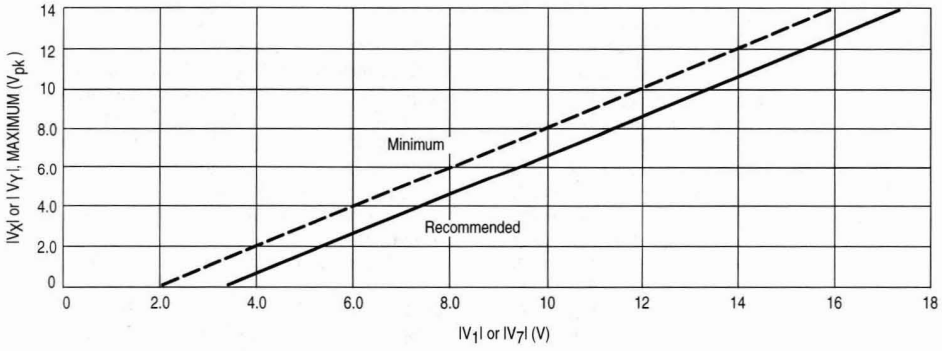



**Figure 19. Maximum Allowable Input Voltage versus Voltage at Pin 1 or Pin 7**

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## OPERATION AND APPLICATIONS INFORMATION

### Theory of Operation

The MC1495 is a monolithic, four-quadrant multiplier which operates on the principle of variable transconductance. A detailed theory of operation is covered in Application Note AN489, *Analysis and Basic Operation of the MC1595*. The result of this analysis is that the differential output current of the multiplier is given by:

$$I_A - I_B = \Delta I = \frac{2V_X V_Y}{R_X R_Y I_3}$$

where, $I_A$ and $I_B$ are the currents into Pins 14 and 2, respectively, and $V_X$ and $V_Y$ are the X and Y input voltages at the multiplier input terminals.

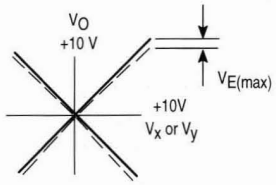
## DESIGN CONSIDERATIONS

### General

The MC1495 permits the designer to tailor the multiplier to a specific application by proper selection of external components. External components may be selected to optimize a given parameter (e.g. bandwidth) which may in turn restrict another parameter (e.g. maximum output voltage swing). Each important parameter is discussed in detail in the following paragraphs.

### Linearity, Output Error, $E_{RX}$ or $E_{RY}$

Linearity error is defined as the maximum deviation of output voltage from a straight line transfer function. It is expressed as error in percent of full scale (see figure below).




For example, if the maximum deviation, $V_{E(max)}$, is ±100 mV and the full scale output is 10 V, then the percentage error is:

$$E_R = \frac{V_{E(max)}}{V_{O(max)}} \times 100 = \frac{100 \times 10^{-3}}{10} \times 100 = \pm 1.0\%.$$

Linearity error may be measured by either of the following methods:

1. Using an X-Y plotter with the circuit shown in Figure 5, obtain plots for X and Y similar to the one shown above.
2. Use the circuit of Figure 4. This method nulls the level shifted output of the multiplier with the original input. The peak output of the null operational amplifier will be equal to the error voltage, $V_{E\ (max)}$.

One source of linearity error can arise from large signal nonlinearity in the X and Y input differential amplifiers. To avoid introducing error from this source, the emitter degeneration resistors $R_X$ and $R_Y$ must be chosen large enough so that nonlinear base-emitter voltage variation can be ignored. Figures 17 and 18 show the error expected from this source as a function of the values of $R_X$ and $R_Y$ with an operating current of 1.0 mA in each side of the differential amplifiers (i.e., $I_3 = I_{13} = 1.0$ mA).

### 3 dB Bandwidth and Phase Shift

Bandwidth is primarily determined by the load resistors and the stray multiplier output capacitance and/or the operational amplifier used to level shift the output. If wideband operation is desired, low value load resistors and/or a wideband operational amplifier should be used. Stray output capacitance will depend to a large extent on circuit layout.

Phase shift in the multiplier circuit results from two sources: phase shift common to both X and Y channels (due to the load resistor-output capacitance pole mentioned above) and relative phase shift between X and Y channels (due to differences in transadmittance in the X and Y channels). If the input to output phase shift is only 0.6°, the output product of two sine waves will exhibit a vector error of 1%. A 3° relative phase shift between $V_X$ and $V_Y$ results in a vector error of 5%.

### Maximum Input Voltage

$V_{X(max)}$, $V_{Y(max)}$ input voltages must be such that:

$$V_{X(max)} < I_{13}\, R_Y$$
$$V_{Y(max)} < I_3\, R_Y$$

Exceeding this value will drive one side of the input amplifier to "cutoff" and cause nonlinear operation.

Current $I_3$ and $I_{13}$ are chosen at a convenient value (observing power dissipation limitation) between 0.5 mA and 2.0 mA, approximately 1.0 mA. Then $R_X$ and $R_Y$ can be determined by considering the input signal handling requirements.

For $V_{X(max)} = V_{Y(max)} = 10$ V;

$$R_X = R_Y > \frac{10\ V}{1.0\ mA} = 10\ k\Omega.$$

The equation $I_A - I_B = \dfrac{2V_X\, V_Y}{R_X\, R_Y\, I_3}$

is derived from $I_A - I_B = \dfrac{2V_X\, V_Y}{(R_X + \frac{2kT}{qI_{13}})\,(R_Y + \frac{2kT}{qI_3})\, I_3}$

with the assumption $R_X >> \dfrac{2kT}{qI_{13}}$ and $R_Y >> \dfrac{2kT}{qI_3}$.

At $T_A = +25°C$ and $I_{13} = I_3 = 1.0$ mA,

$$\frac{2kT}{qI_{13}} = \frac{2kT}{qI_3} = 52\ \Omega.$$

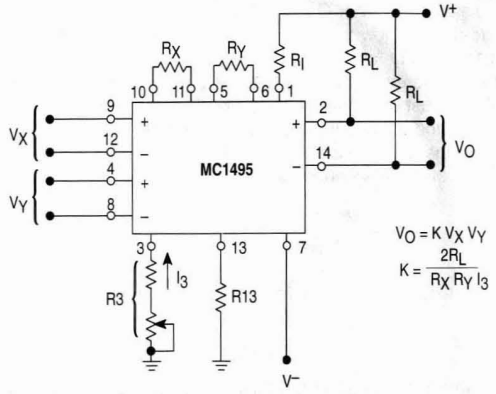
Therefore, with $R_X = R_Y = 10$ kΩ the above assumption is valid. Reference to Figure 19 will indicate limitations of $V_{X(max)}$ or $V_{Y(max)}$ due to $V_1$ and $V_7$. Exceeding these limits will cause saturation or "cutoff" of the input transistors. See Step 4 of General Design Procedure for further details.

### Maximum Output Voltage Swing

The maximum output voltage swing is dependent upon the factors mentioned below and upon the particular circuit being considered.

For Figure 20 the maximum output swing is dependent upon $V^+$ for positive swing and upon the voltage at Pin 1 for negative swing. The potential at Pin 1 determines the quiescent level for transistors $Q_5$, $Q_6$, $Q_7$ and $Q_8$. This potential should be related so that negative swing at Pins 2 or 14 does not saturate those transistors. See General Design Procedure for further information regarding selection of these potentials.

**Figure 20. Basic Multiplier**




If an operational amplifier is used for level shift, as shown in Figure 21, the output swing (of the multiplier) is greatly reduced. See Section 3 for further details.

## GENERAL DESIGN PROCEDURE

Selection of component values is best demonstrated by the following example. Assume resistive dividers are used at the X and Y-inputs to limit the maximum multiplier input to ± 5.0 V [$V_X = V_{Y(max)}$] for a ± 10 V input [$V_{X'} = V_{Y'(max)}$] (see Figure 21). If an overall scale factor of 1/10 is desired,

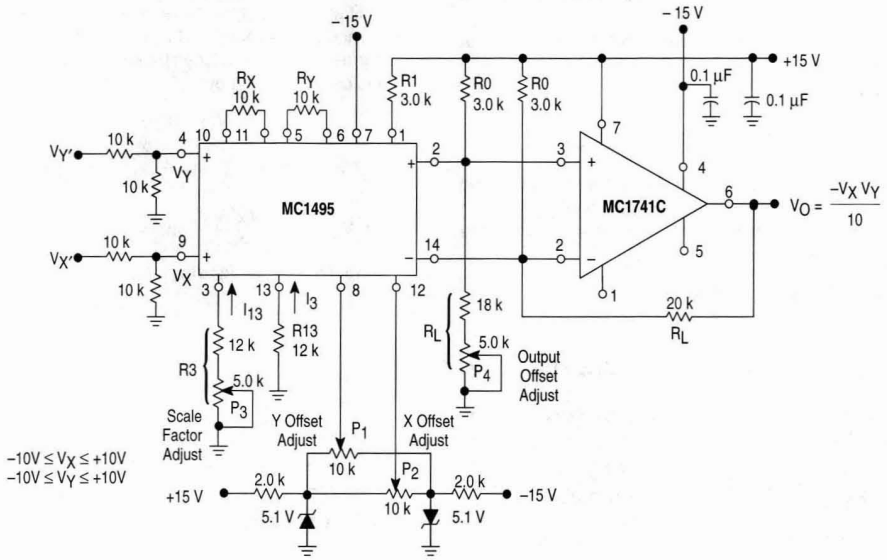
$$\text{then, } V_O = \frac{V_{X'}\,V_{Y'}}{10} = \frac{(2V_X)\,(2V_Y)}{10} = 4/10\ V_X\,V_Y$$

Therefore, K = 4/10 for the multiplier (excluding the divider network).

*Step 1.* The fist step is to select current $I_3$ and current $I_{13}$. There are no restrictions on the selection of either of these currents except the power dissipation of the device. $I_3$ and $I_{13}$ will normally be 1.0 mA or 2.0 mA. Further, $I_3$ does not have to be equal to $I_{13}$, and there is normally no need to make them different. For this example, let

$$I_3 = I_{13} = 1.0\ \text{mA}.$$

**Figure 21. Multiplier with Operational Amplifier Level Shift**

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To set currents $I_3$ and $I_{13}$ to the desired value, it is only necessary to connect a resistor between Pin 13 and ground, and between Pin 3 and ground. From the schematic shown in Figure 3, it can be seen that the resistor values necessary are given by:

$$R13 + 500\ \Omega = \frac{|V-| - 0.7\ V}{I_{13}}$$

$$R3 + 500\ \Omega = \frac{|V-| - 0.7\ V}{I_3}$$

Let V– = –15 V, then $R13 + 500 = \frac{14.3\ V}{1.0\ mA}$ or R13 = 13.8 kΩ

Let $R_{13}$ = 12 kΩ. Similarly, $R_3$ = 13.8 kΩ, let $R_3$ = 15 kΩ

However, for applications which require an accurate scale factor, the adjustment of $R_3$ and consequently, $I_3$, offers a convenient method of making a final trim of the scale factor. For this reason, as shown in Figure 21, resistor $R_3$ is shown as a fixed resistor in series with a potentiometer.

For applications not requiring an exact scale factor (balanced modulator, frequency doubler, AGC amplifier, etc.) Pins 3 and 13 can be connected together and a single resistor from Pin 3 to ground can be used. In this case, the single resistor would have a value of 1/2 the above calculated value for $R_{13}$.

*Step 2.* The next step is to select $R_X$ and $R_Y$. To insure that the input transistors will always be active, the following conditions should be met:

$$\frac{V_X}{R_X} < I_{13}, \qquad \frac{V_Y}{R_Y} < I_3$$

A good rule of thumb is to make $I_3R_Y \geq 1.5\ V_{Y(max)}$ and $I_{13}R_X \geq 1.5 V_{X(max)}$. The larger the $I_3R_Y$ and $I_{13}R_X$ product in relation to $V_Y$ and $V_X$ respectively, the more accurate the multiplier will be (see Figures 17 and 18).

$$\begin{aligned} \text{Let } R_X = R_Y &= 10\ k\Omega, \\ \text{then } I_3R_Y &= 10\ V \\ I_{13}R_X &= 10\ V \end{aligned}$$

since $V_{X(max)} = V_{Y(max)} = 5.0$ V, the value of $R_X = R_Y$ = 10 kΩ is sufficient.

*Step 3.* Now that $R_X$, $R_Y$ and $I_3$ have been chosen, $R_L$ can be determined:

$$K = \frac{2R_L}{R_X R_Y I_3} = \frac{4}{10}\ , \text{or } \frac{(2)\ (R_L)}{(10\ k)\ (10\ k)\ (1.0\ mA)} = \frac{4}{10}$$

Thus $R_L$ = 20 kΩ.

*Step 4.* To determine what power supply voltage is necessary for this application, attention must be given to the circuit schematic shown in Figure 3. From the circuit schematic it can be seen that in order to maintain transistors $Q_1$, $Q_2$, $Q_3$ and $Q_4$ in an active region when the maximum input voltages are applied ($V_{X'} = V_{Y'}$ = 10 V or $V_X$ = 5.0 V, $V_Y$ = 5.0 V), their respective collector voltage should be at least a few tenths of a volt higher than the maximum input voltage. It should also be noticed that the collector voltage of transistors $Q_3$ and $Q_4$ is at a potential which is two diode-drops below the voltage at Pin 1. Thus, the voltage at Pin 1 should be about 2.0 V higher than the maximum input voltage. Therefore, to handle +5.0 V at the inputs, the voltage at Pin 1 must be at least +7.0 V. Let $V_1$ = 9.0 Vdc.

Since the current flowing into Pin 1 is always equal to $2I_3$, the voltage at Pin 1 can be set by placing a resistor ($R_1$) from Pin 1 to the positive supply:

$$R_1 = \frac{V+ - V_1}{2I_3}$$

Let V+ = 15 V, then $R_1 = \frac{15\ V - 9.0\ V}{(2)\ (1.0\ mA)}$

$$R_1 = 3.0\ k\Omega.$$

Note that the voltage at the base of transistors $Q_5$, $Q_6$, $Q_7$ and $Q_8$ is one diode-drop below the voltage at Pin 1. Thus, in order that these transistors stay active, the voltage at Pins 2 and 14 should be approximately halfway between the voltage at Pin 1 and the positive supply voltage. For this example, the voltage at Pins 2 and 14 should be approximately 11 V.

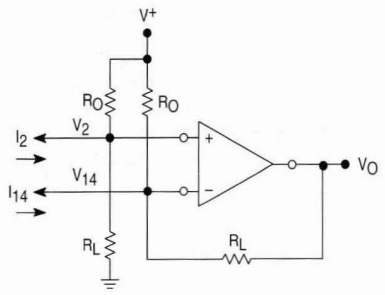
*Step 5.* For dc applications, such as the multiply, divide and square-root functions, it is usually desirable to convert the differential output to a single-ended output voltage referenced to ground. The circuit shown in Figure 22 performs this function. It can be shown that the output voltage of this circuit is given by:

$$V_O = (I_2 - I_{14})\ R_L$$

And since $I_A - I_B = I_2 - I_{14} = \frac{2I_X\ I_Y}{I_3} = \frac{2V_XV_Y}{I_3R_XR_Y}$

then $V_O = \frac{2R_L\ V_X'\ V_Y'}{4R_X\ R_X\ I_3}$ where, $V_X'$ $V_Y'$ is the voltage at the input to the voltage dividers.

**Figure 22. Level Shift Circuit**




The choice of an operational amplifier for this application should have low bias currents, low offset current, and a high common mode input voltage range as well as a high common mode rejection ratio. The MC1456, and MC1741C operational amplifiers meet these requirements.

Referring to Figure 21, the level shift components will be determined. When $V_X = V_Y = 0$, the currents $I_2$ and $I_{14}$ will be equal to $I_{13}$. In Step 3, $R_L$ was found to be 20 kΩ and in Step 4, $V_2$ and $V_{14}$ were found to be approximately 11 V. From this information $R_O$ can be found easily from the following equation (neglecting the operational amplifiers bias current):

$$\frac{V2}{R_L} + I_{13} = \frac{V+ - V_2}{R_O}$$

And for this example, $\frac{11\ V}{20\ k\Omega} + 1.0\ mA = \frac{15\ V - 11\ V}{R_O}$

Solving for $R_O$: $R_O = 2.6\ k\Omega$, thus, select $R_O = 3.0\ k\Omega$

For $R_O = 3.0\ k\Omega$, the voltage at Pins 2 and 14 is calculated to be:

$$V_2 = V_{14} = 10.4\ V.$$

The linearity of this circuit (Figure 21) is likely to be as good or better than the circuit of Figure 5. Further improvements are possible as shown in Figure 23 where $R_Y$ has been increased substantially to improve the Y linearity, and $R_X$ decreased somewhat so as not to materially affect the X linearity. This avoids increasing $R_L$ significantly in order to maintain a K of 0.1.

The versatility of the MC1495 allows the user to to optimize its performance for various input and output signal levels.

## OFFSET AND SCALE FACTOR ADJUSTMENT

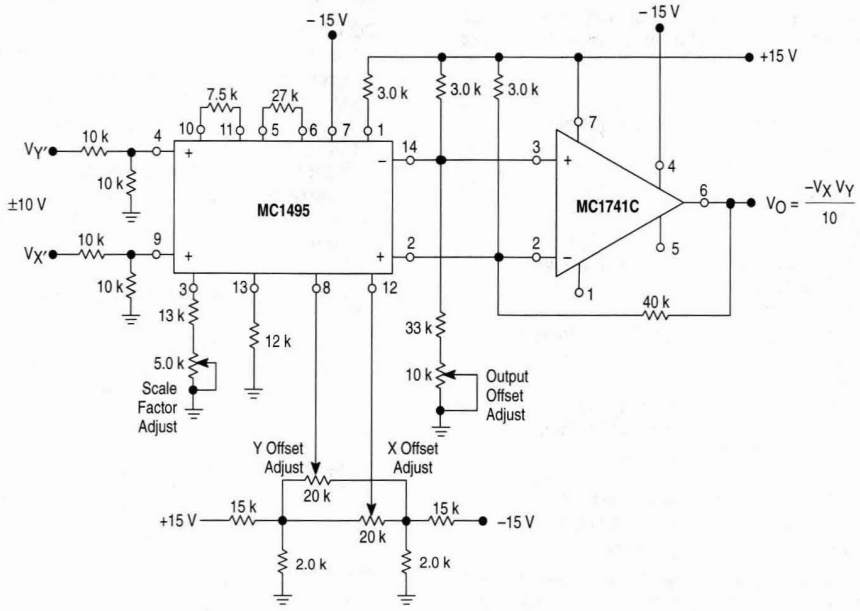
### Offset Voltages

Within the monolithic multiplier (Figure 3) transistor base-emitter junctions are typically matched within 1.0 mV and resistors are typically matched within 2%. Even with this careful matching, an output error can occur. This output error is comprised of X-input offset voltage, Y-input offset voltage, and output offset voltage. These errors can be adjusted to zero with the techniques shown in Figure 21. Offset terms can be shown analytically by the transfer function:

$$V_O = K[V_X \pm V_{iox} \pm V_{x(off)}]\,[V_y \pm V_{ioy} \pm V_{y(off)}] \pm V_{OO} \quad (1)$$

Where:
- $K$ = scale factor
- $V_X$ = "x" input voltage
- $V_y$ = "y" input voltage
- $V_{iox}$ = "x" input offset voltage
- $V_{ioy}$ = "y" input offset voltage
- $V_{x(off)}$ = "x" input offset adjust voltage
- $V_{y(off)}$ = "y" input offset adjust voltage
- $V_{OO}$ = output offset voltage.

**Figure 23. Multiplier with Improved Linearity**

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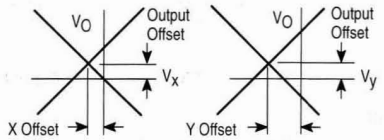
X, Y and Output Offset Voltages




For most dc applications, all three offset adjust potentiometers ($P_1$, $P_2$, $P_4$) will be necessary. One or more offset adjust potentiometers can be eliminated for ac applications (see Figures 28, 29, 30, 31).

If well regulated supply voltages are available, the offset adjust circuit of Figure 13 is recommended. Otherwise, the circuit of Figure 14 will greatly reduce the sensitivity to power supply changes.

### Scale Factor

The scale factor K is set by $P_3$ (Figure 21). $P_3$ varies $I_3$ which inversely controls the scale factor K. It should be noted that current $I_3$ is one-half the current through $R_1$. $R_1$ sets the bias level for $Q_5$, $Q_6$, $Q_7$, and $Q_8$ (see Figure 3). Therefore, to be sure that these devices remain active under all conditions of input and output swing, care should be exercised in adjusting $P_3$ over wide voltage ranges (see General Design Procedure).

### Adjustment Procedures

The following adjustment procedure should be used to null the offsets and set the scale factor for the multiply mode of operation, (see Figure 21).

1. X-Input Offset
   (a) Connect oscillator (1.0 kHz, 5.0 $V_{pp}$ sinewave) to the Y-input (Pin 4).
   (b) Connect X-input (Pin 9) to ground.
   (c) Adjust X offset potentiometer ($P_2$) for an ac null at the output.
2. Y-Input Offset
   (a) Connect oscillator (1.0 kHz, 5.0 $V_{pp}$ sinewave) to the X-input (Pin 9).
   (b) Connect Y-input (Pin 4) to ground.
   (c) Adjust Y offset potentiometer ($P_1$) for an ac null at the output.
3. Output Offset
   (a) Connect both X and Y-inputs to ground.
   (b) Adjust output offset potentiometer ($P_4$) until the output voltage ($V_O$) is 0 Vdc.
4. Scale Factor
   (a) Apply +10 Vdc to both the X and Y-inputs.
   (b) Adjust $P_3$ to achieve + 10 V at the output.
5. Repeat steps 1 through 4 as necessary.

The ability to accurately adjust the MC1495 depends upon the characteristics of potentiometers $P_1$ through $P_4$. Multi-turn, infinite resolution potentiometers with low temperature coefficients are recommended.

## DC APPLICATIONS

### Multiply

The circuit shown in Figure 21 may be used to multiply signals from dc to 100 kHz. Input levels to the actual multiplier are 5.0 V (max). With resistive voltage dividers the maximum could be very large however, for this application two-to-one dividers have been used so that the maximum input level is 10 V. The maximum output level has also been designed for 10 V (max).

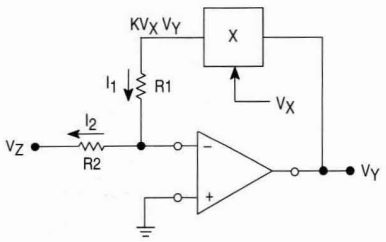
### Squaring Circuit

If the two inputs are tied together, the resultant function is squaring; that is $V_O = KV^2$ where K is the scale factor. Note that all error terms can be eliminated with only three adjustment potentiometers, thus eliminating one of the input offset adjustments. Procedures for nulling with adjustments are given as follows:

A. AC Procedure:
   1. Connect oscillator (1.0 kHz, 15 $V_{pp}$) to input.
   2. Monitor output at 2.0 kHz with tuned voltmeter and adjust $P_3$ for desired gain. (Be sure to peak response of the voltmeter.)
   3. Tune voltmeter to 1.0 kHz and adjust $P_1$ for a minimum output voltage.
   4. Ground input and adjust $P_4$ (output offset) for 0 Vdc output.
   5. Repeat steps 1 through 4 as necessary.

B. DC Procedure:
   1. Set $V_X = V_Y = 0$ V and adjust $P_4$ (output offset potentiometer) such that $V_O = 0$ Vdc
   2. Set $V_X = V_Y = 1.0$ V and adjust $P_1$ (Y-input offset potentiometer) such that the output voltage is + 0.100 V.
   3. Set $V_X = V_Y = 10$ Vdc and adjust $P_3$ such that the output voltage is + 10 V.
   4. Set $V_X = V_Y = -10$ Vdc. Repeat steps 1 through 3 as necessary.

**Figure 24. Basic Divide Circuit**

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### Divide Circuit

Consider the circuit shown in Figure 24 in which the multiplier is placed in the feedback path of an operational amplifier. For this configuration, the operational amplifier will maintain a "virtual ground" at the inverting (–) input. Assuming that the bias current of the operational amplifier is negligible, then $I_1 = I_2$ and,

$$\frac{KV_XV_Y}{R1} = \frac{-V_Z}{R2} \quad (1)$$

$$\text{Solving for } V_Y, \quad V_Y = \frac{-R1}{R2\,K}\,\frac{V_Z}{V_X} \quad (2)$$

$$\text{If } R1=R2, \quad V_Y = \frac{-V_Z}{KV_X} \quad (3)$$

$$\text{If } R1=KR2, \quad V_Y = \frac{-V_Z}{V_X} \quad (4)$$

Hence, the output voltage is the ratio of $V_Z$ to $V_X$ and provides a divide function. This analysis is, of course, the ideal condition. If the multiplier error is taken into account, the output voltage is found to be:

$$V_Y = -\left[\frac{R1}{R2\,K}\right]\frac{V_Z}{V_X} + \frac{\Delta E}{KV_X} \quad (5)$$

where $\Delta E$ is the error voltage at the output of the multiplier. From this equation, it is seen that divide accuracy is strongly dependent upon the accuracy at which the multiplier can be set, particularly at small values of $V_Y$. For example, assume that R1 = R2, and K = 1/10. For these conditions the output of the divide circuit is given by:

$$V_Y = \frac{-10\,V_Z}{V_X} + \frac{10\,\Delta E}{V_X} \quad (6)$$

From Equation 6, it is seen that only when $V_X = 10$ V is the error voltage of the divide circuit as low as the error of the multiply circuit. For example, when $V_X$ is small, (0.1 V) the error voltage of the divide circuit can be expected to be a hundred times the error of the basic multiplier circuit.

In terms of percentage error,

$$\text{percentage error} = \frac{\text{error}}{\text{actual}} \times 100\%$$

or from Equation (5),

$$PE_D = \frac{\frac{\Delta E}{KV_X}}{\left[\frac{R1}{R2\,K}\right]\frac{V_Z}{V_X}} = \left[\frac{R2}{R1}\right]\frac{\Delta E}{V_Z} \quad (7)$$

From Equation 7, the percentage error is inversely related to voltage $V_Z$ (i.e., for increasing values of $V_Z$, the percentage error decreases).

A circuit that performs the divide function is shown in Figure 25.

Two things should be emphasized concerning Figure 25.

1. The input voltage ($V_{X'}$) must be greater than zero and must be positive. This insures that the current out of Pin 2 of the multiplier will always be in a direction compatible with the polarity of $V_Z$.
2. Pin 2 and 14 of the multiplier have been interchanged in respect to the operational amplifiers input terminals. In this instance, Figure 25 differs from the circuit connection shown in Figure 21; necessitated to insure negative feedback around the loop.

A suggested adjustment procedure for the divide circuit.

1. Set $V_Z = 0$ V and adjust the output offset potentiometer ($P_4$) until the output voltage ($V_O$) remains at some (not necessarily zero) constant value as $V_{X'}$ is varied between +1.0 V and +10 V.
2. Keep $V_Z$ at 0 V, set $V_{X'}$ at +10 V and adjust the Y input offset potentiometer ($P_1$) until $V_O = 0$ V.
3. Let $V_{X'} = V_Z$ and adjust the X-input offset potentiometer ($P_2$) until the output voltage remains at some (not necessarily – 10 V) constant value as $V_Z = V_{X'}$ is varied between +1.0 and +10 V.
4. Keep $V_{X'} = V_Z$ and adjust the scale factor potentiometer ($P_3$) until the average value of $V_O$ is –10 V as $V_Z = V_{X'}$ is varied between +1.0 V and +10 V.
5. Repeat steps 1 through 4 as necessary to achieve optimum performance.

**Figure 25. Divide Circuit**

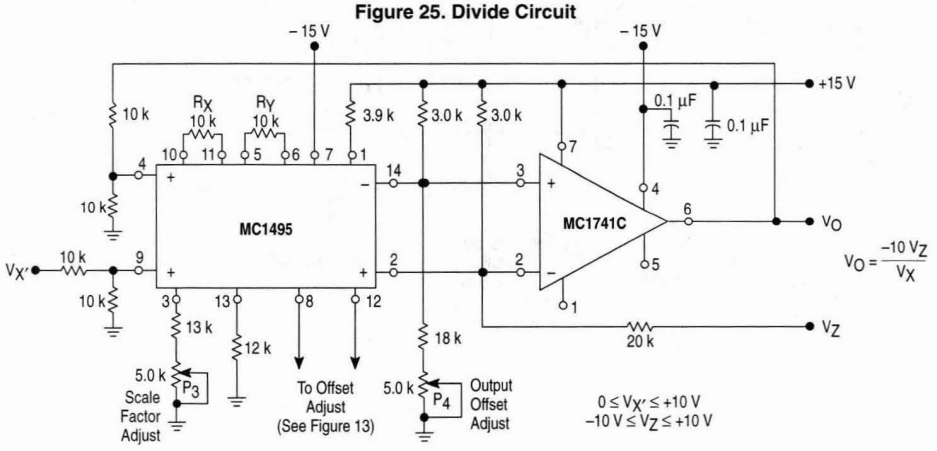
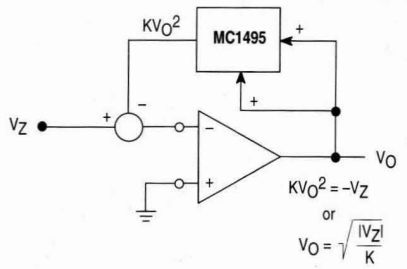


**Figure 26. Basic Square Root Circuit**




### Square Root

A special case of the divide circuit in which the two inputs to the multiplier are connected together is the square root function as indicated in Figure 26. This circuit may suffer from latch-up problems similar to those of the divide circuit. Note that only one polarity of input is allowed and diode clamping (see Figure 27) protects against accidental latch-up.

This circuit also may be adjusted in the closed-loop mode as follows:

1. Set $V_Z$ to –0.01 V and adjust $P_4$ (output offset) for $V_O$ = +0.316 V, being careful to approach the output from the positive side to preclude the effect of the output diode clamping.
2. Set $V_Z$ to –0.9 V and adjust $P_2$ (X adjust) for $V_O$ = +3.0 V.
3. Set $V_Z$ to –10 V and adjust $P_3$ (scale factor adjust) for $V_O$ = +10 V.
4. Steps 1 through 3 may be repeated as necessary to achieve desired accuracy.

### AC APPLICATIONS

The applications that follow demonstrate the versatility of the monolithic multiplier. If a potted multiplier is used for these cases, the results generally would not be as good because the potted units have circuits that, although they optimize dc multiplication operation, can hinder ac applications.

Frequency doubling often is done with a diode where the fundamental plus a series of harmonics are generated. However, extensive filtering is required to obtain the desired harmonic, and the second harmonic obtained under this technique usually is small in magnitude and requires amplification.

When a multiplier is used to double frequency the second harmonic is obtained directly, except for a dc term, which can be removed with ac coupling.

$$e_o = KE^2 \cos^2 \omega t$$

$$e_o = \frac{KE^2}{2} (1 + \cos 2\omega t).$$

A potted multiplier can be used to obtain the double frequency component, but frequency would be limited by its internal level-shift amplifier. In the monolithic units, the amplifier is omitted.

In a typical doubler circuit, conventional ± 15 V supplies are used. An input dynamic range of 5.0 V peak-to-peak is allowed. The circuit generates wave-forms that are double frequency; less than 1% distortion is encountered without filtering. The configuration has been successfully used in excess of 200 kHz; reducing the scale factor by decreasing the load resistors can further expand the bandwidth.

Figure 29 represents an application for the monolithic multiplier as a balanced modulator. Here, the audio input signal is 1.6 kHz and the carrier is 40 kHz.

**Figure 27. Square Root Circuit**

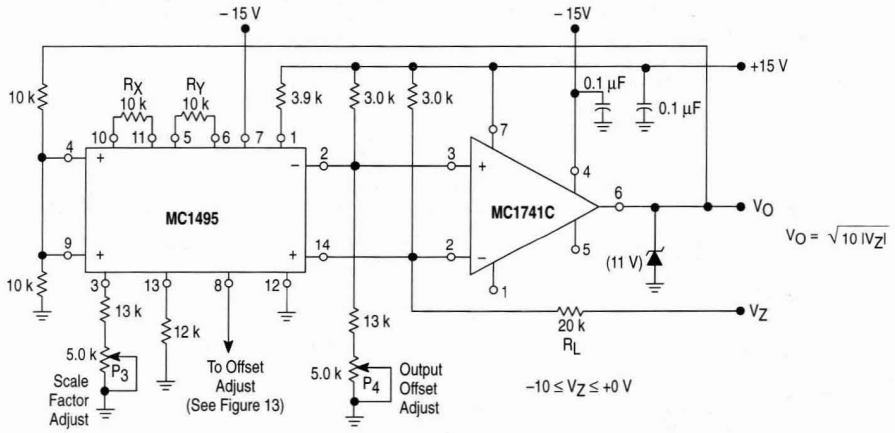
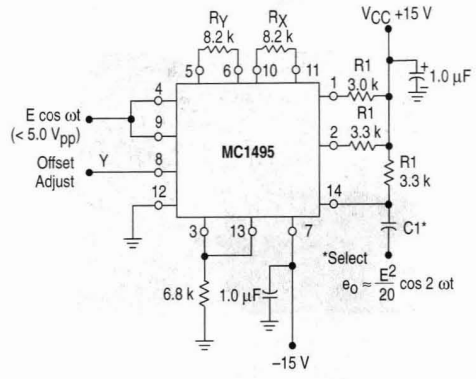


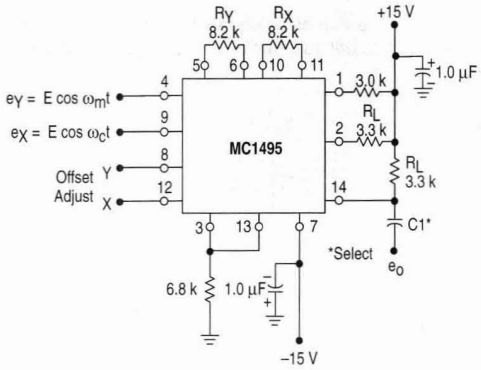
**Figure 28. Frequency Doubler**



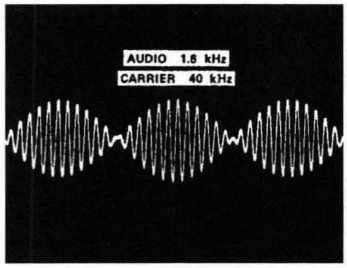

When two equal cosine waves are applied to X and Y, the result is a wave shape of twice the input frequency. For this example the input was a 10 kHz signal, output was 20 kHz.

**Figure 29. Balanced Modulator**

**(A)**




**(B)**




The defining equation for balanced modulation is

$$K(E_m \cos \omega_m t)(E_c \cos \omega_c t) =$$

$$\frac{KE_c E_m}{2} [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

where $\omega_c$ is the carrier frequency, $\omega_m$ is the modulator frequency and K is the multiplier gain constant.

AC coupling at the output eliminates the need for level translation or an operational amplifier; a higher operating frequency results.

A problem common to communications is to extract the intelligence from single-sideband received signal. The ssb signal is of the form:

$$e_{ssb} = A \cos(\omega_c + \omega_m)t$$

and if multiplied by the appropriate carrier waveform, $\cos \omega_c t$,

$$e_{ssb} e_{carrier} = \frac{AK}{2} [\cos(2\omega_c + \omega_m)t + \cos(\omega_c)t].$$

If the frequency of the band-limited carrier signal ($\omega_c$) is ascertained in advance, the designer can insert a low pass filter and obtain the (AK/2) ($\cos\omega_c t$) term with ease. He/she also can use an operational amplifier for a combination level shift-active filter, as an external component. But in potted multipliers, even if the frequency range can be covered, the operational amplifier is inside and not accessible, so the user must accept the level shifting provided, and still add a low pass filter.

**Amplitude Modulation**

The multiplier performs amplitude modulation, similar to balanced modulation, when a dc term is added to the modulating signal with the Y-offset adjust potentiometer (see Figure 30).

Here, the identity is:

$$E_m(1 + m \cos \omega_m t) E_c \cos \omega_c t = KE_m E_c \cos \omega_c t +$$

$$\frac{KE_m E_c m}{2} [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

where m indicates the degrees of modulation. Since m is adjustable, via potentiometer $P_1$, 100% modulation is possible. Without extensive tweaking, 96% modulation may be obtained where $\omega_c$ and $\omega_m$ are the same as in the balanced modulator example.

**Linear Gain Control**

To obtain linear gain control, the designer can feed to one of the two MC1495 inputs a signal that will vary the unit's gain. The following example demonstrates the feasibility of this application. Suppose a 200 kHz sinewave, 1.0 V peak-to-peak, is the signal to which a gain control will be added. The dynamic range of the control voltage $V_C$ is 0 V to +1.0 V. These must be ascertained and the proper values of $R_X$ and $R_Y$ can be selected for optimum performance. For the 200 kHz operating frequency, load resistors of 100 Ω were chosen to broaden the operating bandwidth of the multiplier, but gain was sacrificed. It may be made up with an amplifier operating at the appropriate frequency (see Figure 31).

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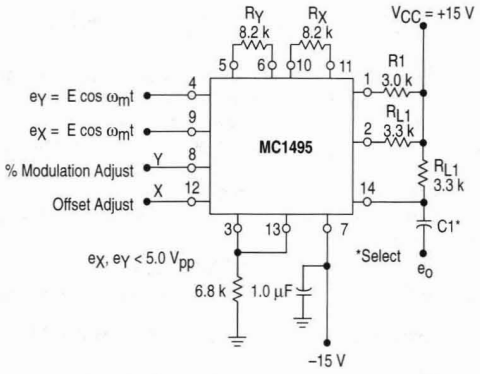
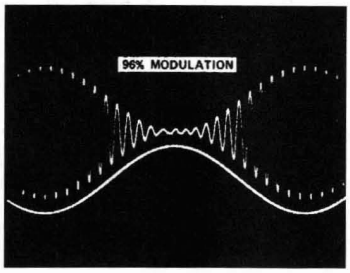
**Figure 30. Amplitude Modulation**




The signal is applied to the unit's Y-input. Since the total input range is limited to 1.0 $V_{pp}$, a 2.0 V swing, a current source of 2.0 mA and an $R_Y$ value of 1.0 kΩ is chosen. This takes best advantage of the dynamic range and insures linear operation in the Y-channel.

Since the X-input varies between 0 and +1.0 V, the current source selected was 1.0 mA, and the $R_X$ value chosen was 2.0 kΩ. This also insures linear operation over the X-input dynamic range. Choosing $R_L$ = 100 assures wide bandwidth operation.

Hence, the scale factor for this configuration is:

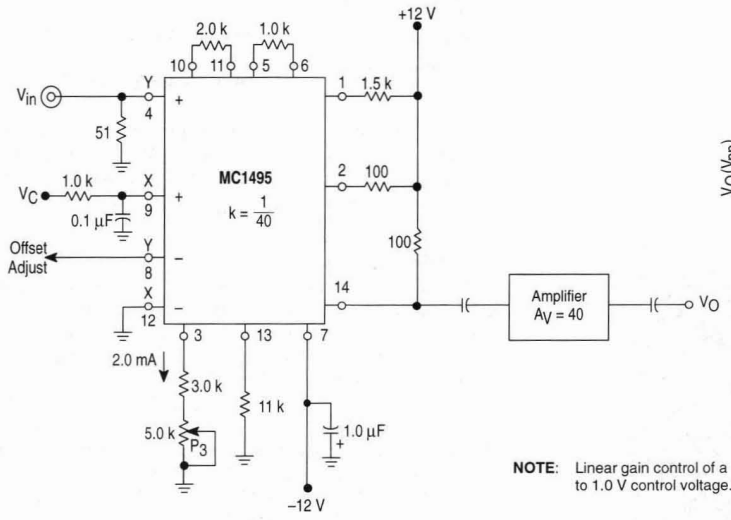
$$K = \frac{R_L}{R_X R_Y I_3}$$

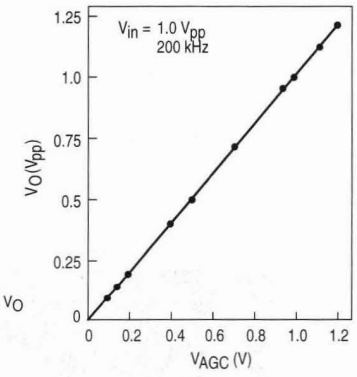
$$= \frac{100}{(2\text{ k})(1\text{ k})(2 \times 10^3)}\ V^{-1}$$

$$= \frac{1}{40}\ V^{-1}$$

The 2 in the numerator of the equation is missing in this scale factor expression because the output is single-ended and ac coupled.

**Figure 31. Linear Gain Control**




**NOTE:** Linear gain control of a 1.0 $V_{pp}$ signal is performed with a 0 V to 1.0 V control voltage. If $V_C$ is 0.5 V the output will be 0.5 $V_{pp}$.

MOTOROLA

# MC3456

# Dual Timing Circuit

**DUAL TIMING CIRCUIT**

**SEMICONDUCTOR TECHNICAL DATA**

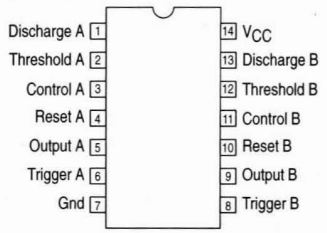
The MC3456 dual timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor per timer. For astable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor per timer. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200 mA or drive MTTL circuits.

- Direct Replacement for NE556/SE556 Timers
- Timing from Microseconds through Hours
- Operates in Both Astable and Monostable Modes
- Adjustable Duty Cycle
- High Current Output can Source or Sink 200 mA
- Output can Drive MTTL
- Temperature Stability of 0.005% per °C
- Normally "On" or Normally "Off" Output
- Dual Version of the Popular MC1455 Timer

**P SUFFIX**
PLASTIC PACKAGE
CASE 646

**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–14)

**PIN CONNECTIONS**

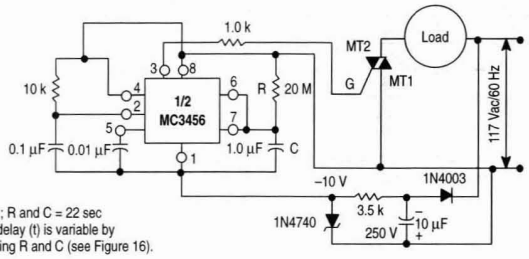



(Top View)

**ORDERING INFORMATION**

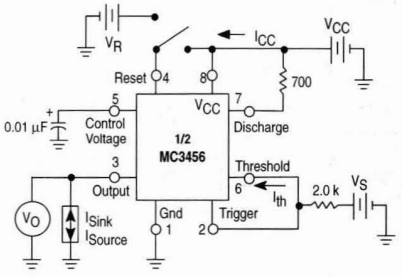
| Device | Operating Temperature Range | Package |
|---|---|---|
| MC3456P | 0° to +70°C | Plastic DIP |
| NE556D | | SO–14 |

**Figure 1. 22 Second Solid State Time Delay Relay Circuit**



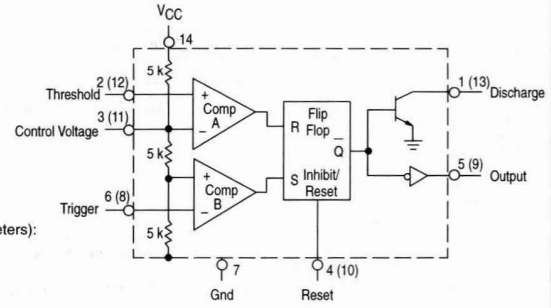

t = 1.1; R and C = 22 sec
Time delay (t) is variable by changing R and C (see Figure 16).

**Figure 3. General Test Circuit**




Test circuit for measuring DC parameters (to set output and measure parameters):
a) When $V_S \geq 2/3\ V_{CC}$, $V_O$ is low.
b) When $V_S \leq 1/3\ V_{CC}$, $V_O$ is high.
c) When $V_O$ is low, Pin 7 sinks current. To test for Reset, set $V_O$ high, apply Reset voltage, and test for current flowing into Pin 7. When Reset is not in use, it should be tied to $V_{CC}$.

**Figure 2. Block Diagram** (1/2 Shown)

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**MAXIMUM RATINGS** ($T_A$ = +25°C, unless otherwise noted.)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$ | +18 | Vdc |
| Discharge Current | $I_{dis}$ | 200 | mA |
| Power Dissipation (Package Limitation)<br>P Suffix, Plastic Package, Case 646<br>Derate above $T_A$ = +25°C<br>D Suffix, Plastic Package, Case 751<br>Derate above $T_A$ = +25°C | $P_D$ | <br>625<br>5.0<br>1.0<br>8.0 | <br>mW<br>mW/°C<br>W<br>mW/°C |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_A$ = +25°C, $V_{CC}$ = +15 V, unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Supply Voltage | $V_{CC}$ | 4.5 | – | 16 | V |
| Supply Current<br>$V_{CC}$ = 5.0 V, $R_L$ = ∞<br>$V_{CC}$ = 15 V, $R_L$ = ∞ Low State, (Note 1) | $I_{CC}$ | <br>–<br>– | <br>6.0<br>20 | <br>12<br>30 | mA |
| Timing Error (Note 2)<br>Monostable Mode ($R_A$ = 2.0 kΩ; C = 0.1 μF)<br>Initial Accuracy<br>Drift with Temperature<br>Drift with Supply Voltage<br>Astable Mode ($R_A$ = $R_B$ = 2.0 kΩ to 100 kΩ; C = 0.01 μF)<br>Initial Accuracy<br>Drift with Temperature<br>Drift with Supply Voltage | | <br><br>–<br>–<br>–<br><br>–<br>–<br>– | <br><br>0.75<br>50<br>0.1<br><br>2.25<br>150<br>0.3 | <br><br>–<br>–<br>–<br><br>–<br>–<br>– | <br><br>%<br>PPM/°C<br>%/V<br><br>%<br>PPM/°C<br>%/V |
| Threshold Voltage | $V_{th}$ | – | 2/3 | – | x$V_{CC}$ |
| Trigger Voltage<br>$V_{CC}$ = 15 V<br>$V_{CC}$ = 5.0 V | $V_T$ | <br>–<br>– | <br>5.0<br>1.67 | <br>–<br>– | V |
| Trigger Current | $I_T$ | – | 0.5 | – | μA |
| Reset Voltage | $V_R$ | 0.4 | 0.7 | 1.0 | V |
| Reset Current | $I_R$ | – | 0.1 | – | mA |
| Threshold Current (Note 3) | $I_{th}$ | – | 0.03 | 0.1 | μA |
| Control Voltage Level<br>$V_{CC}$ = 15 V<br>$V_{CC}$ = 5.0 V | $V_{CL}$ | <br>9.0<br>2.6 | <br>10<br>3.33 | <br>11<br>4.0 | V |
| Output Voltage Low<br>($V_{CC}$ = 15 V)<br>$I_{Sink}$ = 10 mA<br>$I_{Sink}$ = 50 mA<br>$I_{Sink}$ = 100 mA<br>$I_{Sink}$ = 200 mA<br>($V_{CC}$ = 5.0 V)<br>$I_{Sink}$ = 5.0 mA | $V_{OL}$ | <br><br>–<br>–<br>–<br>–<br><br>– | <br><br>0.1<br>0.4<br>2.0<br>2.5<br><br>0.25 | <br><br>0.25<br>0.75<br>2.75<br>–<br><br>0.35 | V |
| Output Voltage High<br>($I_{Source}$ = 200 mA)<br>$V_{CC}$ = 15 V<br>($I_{Source}$ = 100 mA)<br>$V_{CC}$ = 15 V<br>$V_{CC}$ = 5.0 V | $V_{OH}$ | <br>–<br><br>12.75<br>2.75 | <br>12.5<br><br>13.3<br>3.3 | <br>–<br><br>–<br>– | V |
| Toggle Rate $R_A$ = 3.3 kΩ, $R_B$ = 6.8 kΩ, C = 0.003 μF (Figure 17, 19) | – | – | 100 | – | kHz |
| Discharge Leakage Current | $I_{dis}$ | – | 20 | 100 | nA |
| Rise Time of Output | $t_{OLH}$ | – | 100 | – | ns |
| Fall Time of Output | $t_{OHL}$ | – | 100 | – | ns |
| Matching Characteristics Between Sections<br>Monostable Mode<br>Initial Timing Accuracy<br>Timing Drift with Temperature<br>Drift with Supply Voltage | | <br><br>–<br>–<br>– | <br><br>1.0<br>±10<br>0.2 | <br><br>2.0<br>–<br>0.5 | <br><br>%<br>ppm/°C<br>%/V |

**NOTES:** 1. Supply current is typically 1.0 mA less for each output which is high.
2. Tested at $V_{CC}$ = 5.0 V and $V_{CC}$ = 15 V.
3. This will determine the maximum value of $R_A$ + $R_B$ for 15 V operation. The maximum total R = 20 mΩ.

**Figure 4. Trigger Pulse Width**

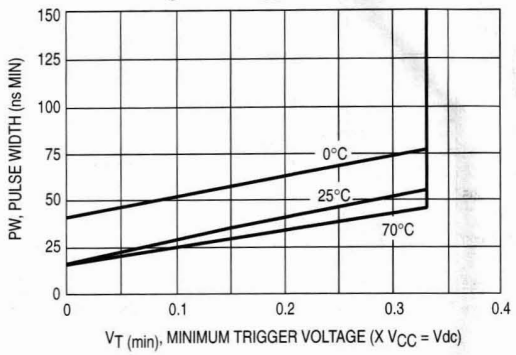


**Figure 5. Supply Current**

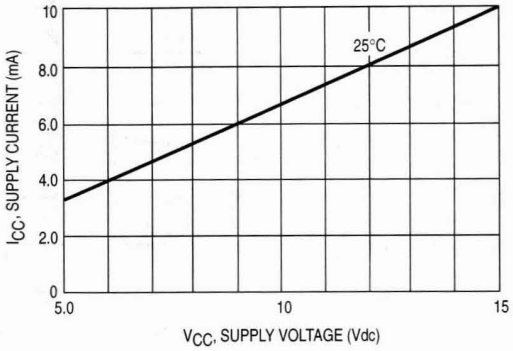


**Figure 6. High Output Voltage**

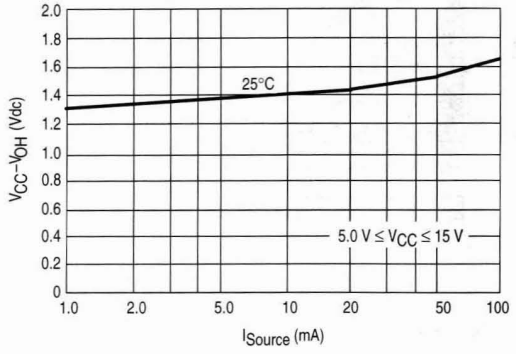


**Figure 7. Low Output Voltage**
(@ $V_{CC}$ = 5.0 Vdc)

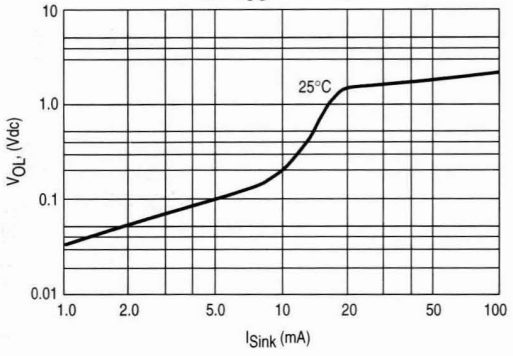


**Figure 8. Low Output Voltage**
(@ $V_{CC}$ = 10 Vdc)

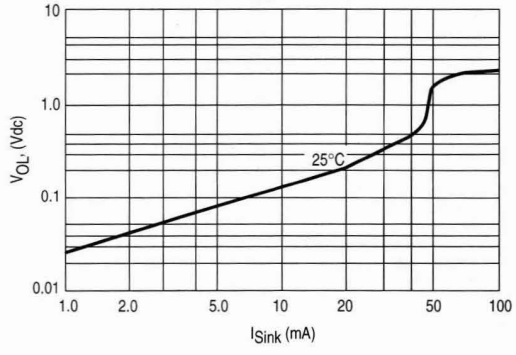


**Figure 9. Low Output Voltage**
(@ $V_{CC}$ = 15 Vdc)

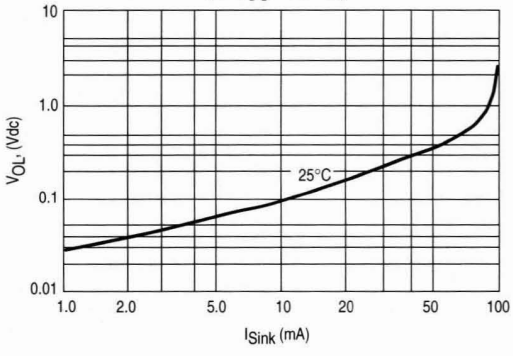


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**Figure 10. Delay Time versus Supply Voltage**

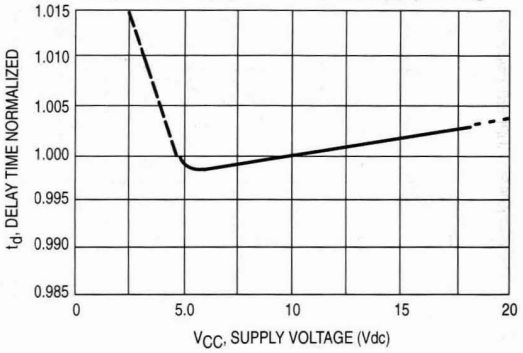



**Figure 11. Delay Time versus Temperature**

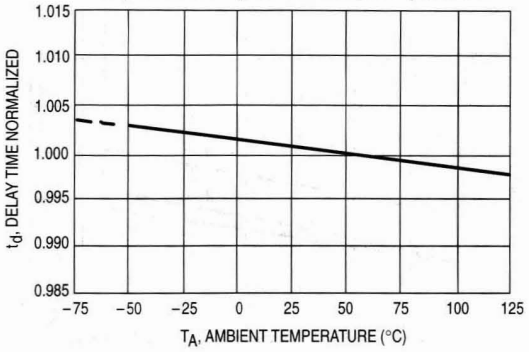
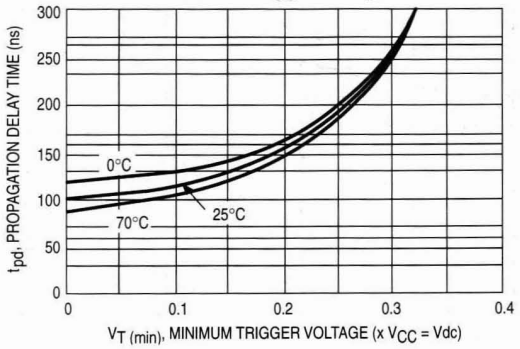
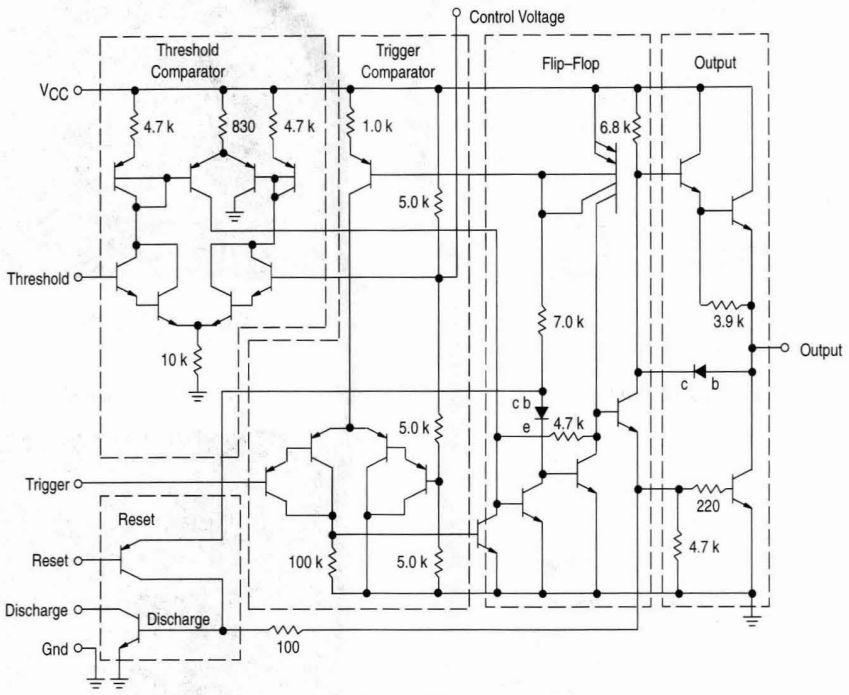



**Figure 12. Propagation Delay versus Trigger Voltage**




11

**Figure 13. 1/2 Representative Circuit Schematic**




## GENERAL OPERATION

The MC3456 is a dual timing circuit which uses as its timing elements an external resistor/capacitor network. It can be used in both the monostable (one shot) and astable modes with frequency and duty cycle, controlled by the capacitor and resistor values. While the timing is dependent upon the external passive components, the monolithic circuit provides the starting circuit, voltage comparison and other functions needed for a complete timing circuit. Internal to the integrated circuit are two comparators, one for the input signal and the other for capacitor voltage; also a flip–flop and digital output are included. The comparator reference voltages are always a fixed ratio of the supply voltage thus providing output timing independent of supply voltage.

### Monostable Mode

In the monostable mode, a capacitor and a single resistor are used for the timing network. Both the threshold terminal and the discharge transistor terminal are connected together in this mode (refer to circuit Figure 15). When the input voltage to the trigger comparator falls below 1/3 $V_{CC}$ the comparator output triggers the flip–flop so that it's output sets low. This turns the capacitor discharge transistor "off" and drives the digital output to the high state. This condition allows the capacitor to charge at an exponential rate which is set by the RC time constant. When the capacitor voltage reaches 2/3 $V_{CC}$ the threshold comparator resets the flip–flop. This action discharges the timing capacitor and returns the digital output to the low state. Once the flip–flop has been triggered by an input signal, it cannot be retriggered until the present timing period has been completed. The time that the output is high is given by the equation $t = 1.1\ R_A\ C$. Various combinations of R and C and their associated times are shown in Figure 14. The trigger pulse width must be less than the timing period.

A reset pin is provided to discharge the capacitor thus interrupting the timing cycle. As long as the reset pin is low, the capacitor discharge transistor is turned "on" and prevents the capacitor from charging. While the reset voltage is applied the digital output will remain the same. The reset pin should be tied to the supply voltage when not in use.

**Figure 14. Time Delay**

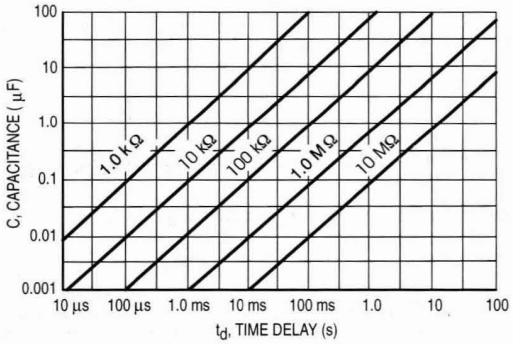
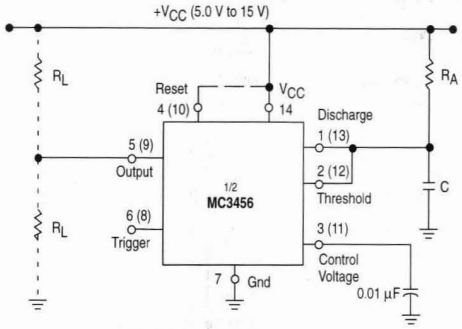
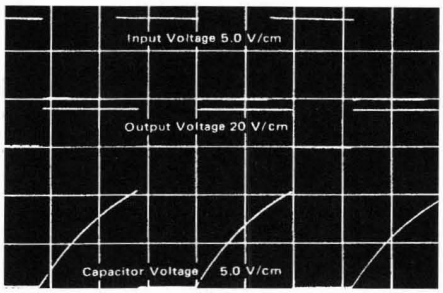


**Figure 15. Monostable Circuit**




Pin numbers in parenthesis ( ) indicate B–Channel

**Figure 16. Monostable Waveforms**




t = 50 µs/cm
($R_A$ = 10 kΩ, C = 0.01 µF, $R_L$ = 1.0 kΩ, $V_{CC}$ = 15 V)

**Figure 17. Astable Circuit**

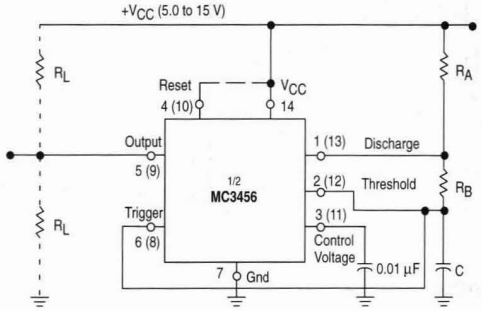
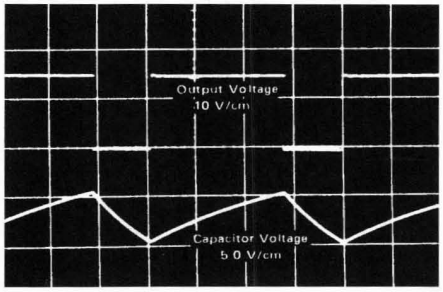



**Figure 18. Astable Waveforms**




t = 20 µs/cm
($R_A$ = 5.1 kΩ, C = 0.0 1 µF, $R_L$ = 1.0 kΩ, $R_B$ = 3.9 kΩ, $V_{CC}$ = 15 V)

**Astable Mode**

In the astable mode the timer is connected so that it will retrigger itself and cause the capacitor voltage to oscillate between 1/3 $V_{CC}$ and 2/3 $V_{CC}$ (see Figure 17).

The external capacitor charges to 2/3 $V_{CC}$ through $R_A$ and $R_B$ and discharges to 1/3 $V_{CC}$ through $R_B$. By varying the ratio of these resistors the duty cycle can be varied. The charge and discharge times are independent of the supply voltage.

The charge time (output high) is given by:

$$t_1 = 0.695\ (R_A + R_B)\ C$$

The discharge time (output low) by:

$$t_2 = 0.695\ (R_B)\ C$$

Thus the total period is given by:

$$T = t_1 + t_2 = 0.695\ (R_A + 2R_B)\ C$$

The frequency of oscillation is then: $f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B)\ C}$

and may be easily found as shown in Figure 19.

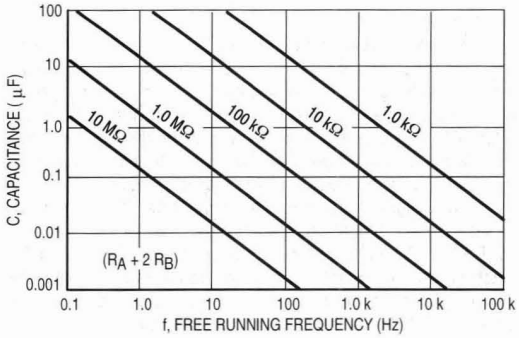
The duty cycle is given by: $DC = \frac{R_B}{R_A + 2R_B}$

To obtain the maximum duty cycle, $R_A$ must be as small as possible; but it must also be large enough to limit the discharge current (Pin 7 current) within the maximum rating of the discharge transistor (200 mA).

The minimum value of $R_A$ is given by:

$$R_A \geq \frac{V_{CC}\ (Vdc)}{I_7\ (A)} \geq \frac{V_{CC}\ (Vdc)}{0.2}$$

**Figure 19. Free Running Frequency**



## APPLICATIONS INFORMATION

### Tone Burst Generator

For a tone burst generator, the first timer is used as a monostable and determines the tone duration when triggered by a positive pulse at Pin 6. The second timer is enabled by the high output of the monostable. It is connected as an astable and determines the frequency of the tone.

### Dual Astable Multivibrator

This dual astable multivibrator provides versatility not available with single timer circuits. The duty cycle can be adjusted from 5% to 95%. The two outputs provide two phase clock signals often required in digital systems. It can also be inhibited by use of either reset terminal.

**Figure 20. Tone Burst Generator**

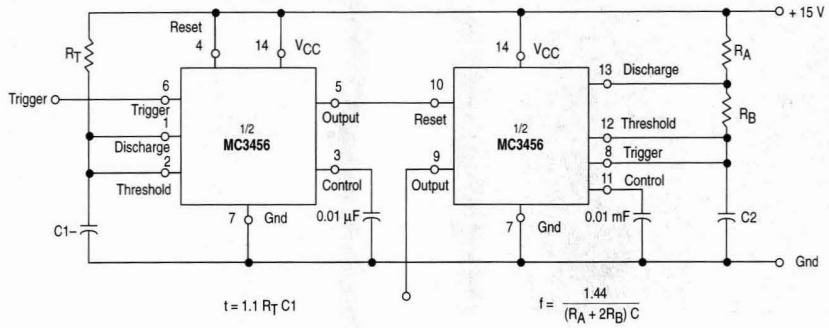
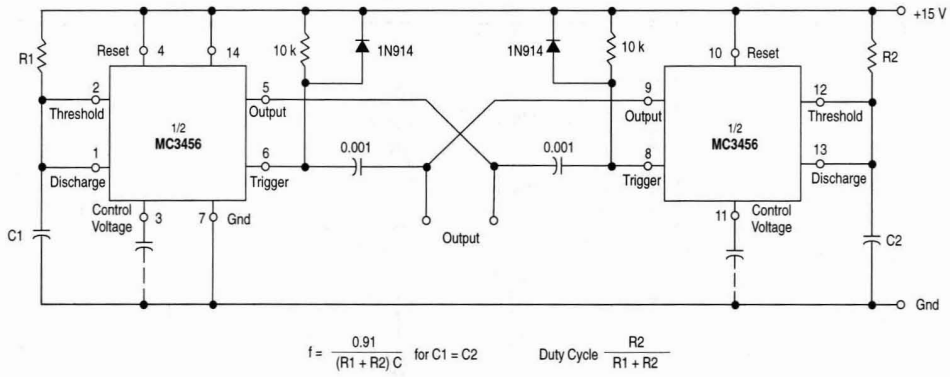



**Figure 21. Dual Astable Multivibrator**

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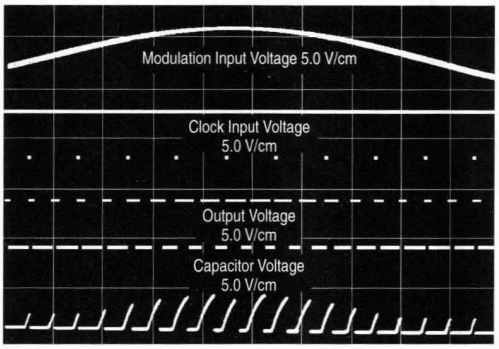
### Pulse Width Modulation

If the timer is triggered with a continuous pulse train in the monostable mode of operation, the charge time of the capacitor can be varied by changing the control voltage at Pin 3. In this manner, the output pulse width can be modulated by applying a modulating signal that controls the threshold voltage.

### Test Sequences

Several timers can be connected to drive each other for sequential timing. An example is shown in Figure 24 where the sequence is started by triggering the first timer which runs for 10 ms. The output then switches low momentarily and starts the second timer which runs for 50 ms and so forth.

**Figure 22. Pulse Width Modulation Waveforms**




t = 0.5 ms/cm
($R_A$ = 10 kW, C = 0.02 mF, $V_{CC}$ = 15 V)

**Figure 23. Pulse Width Modulation Circuit**

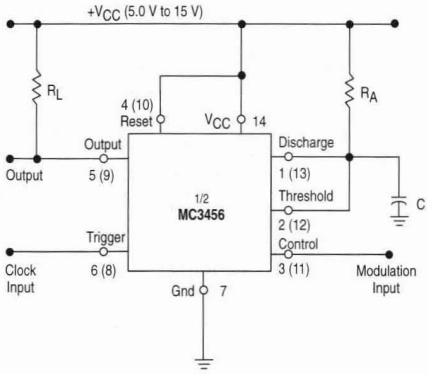
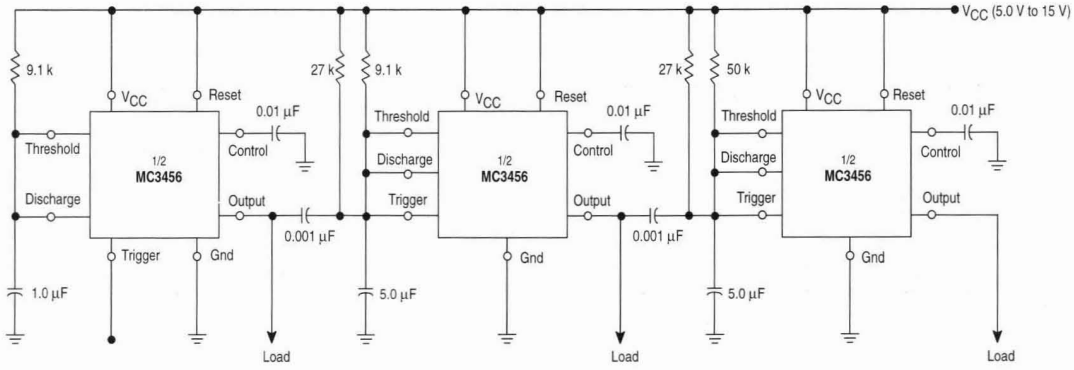



**Figure 24. Sequential Timing Circuit**



# Tape and Reel Options

## In Brief . . .

Motorola offers the convenience of Tape and Reel packaging for our growing family of standard integrated circuit products. Reels are available to support the requirements of both first and second generation pick–and–place equipment. The packaging fully conforms to the latest EIA–481A specification. The antistatic embossed tape provides a secure cavity, sealed with a peel–back cover tape.


| | Page |
|---|---|
| Tape and Reel Configurations | 12–2 |
| Tape and Reel Information Table | 12–4 |
| Analog MPQ Table | 12–5 |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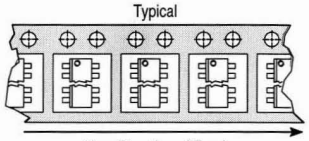
# Tape and Reel Configurations

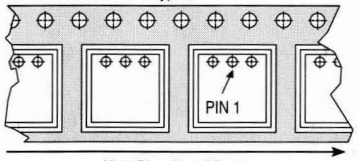
**Mechanical Polarization**

**SOIC and Micro–8 DEVICES**
Typical



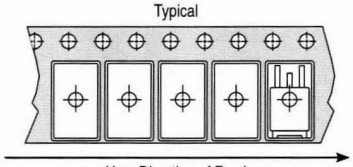
User Direction of Feed

**PLCC DEVICES**
Typical



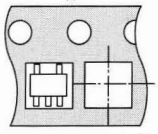

User Direction of Feed

**DPAK and D²PAK DEVICES**
Typical



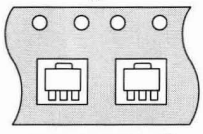
User Direction of Feed

**SOT–23 (5 Pin) DEVICES**
Typical



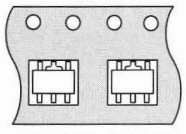
User Direction of Feed

**SOT–89 (3 Pin) DEVICES**
Typical



User Direction of Feed

**SOT–89 (5 Pin) DEVICES**
Typical



User Direction of Feed

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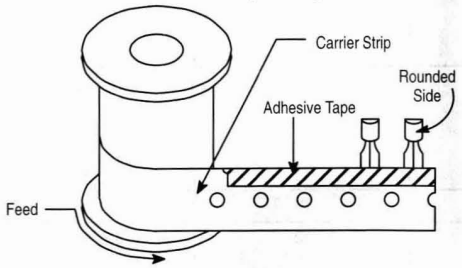
## Tape and Reel Configurations (continued)

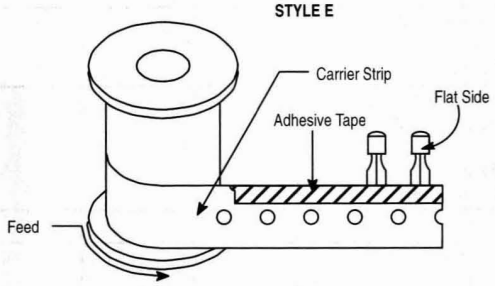
### TO–92 Reel Styles

**STYLE A**
**(Preferred)**




Rounded side of transistor and adhesive tape visible.

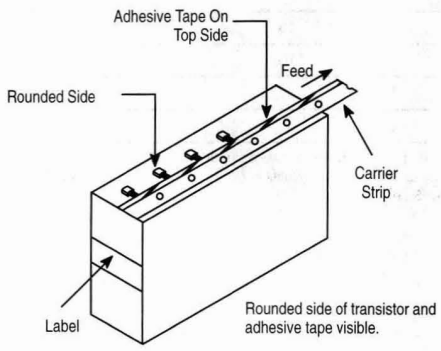
**STYLE E**




Flat side of transistor and adhesive tape visible.

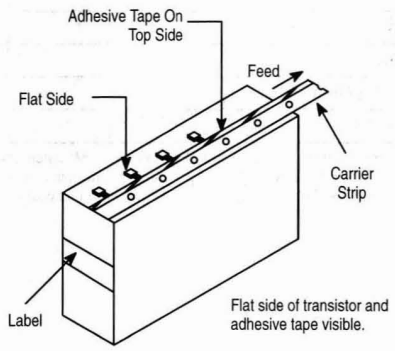
### TO–92 Ammo Pack Styles

**STYLE P**
**(Preferred)**



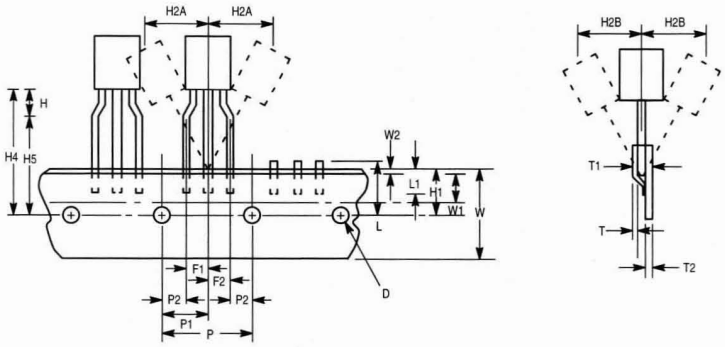

Style P ammo pack is equivalent to Styles A and B of reel pack dependent on feed orientation from box.

**STYLE M**




Style M ammo pack is equivalent to Style E of reel pack dependent on feed orientation from box.

### TO–92 EIA Radial Tape in Fan Fold Box or On Reel

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# Tape and Reel Information Table

| Package | Tape Width (mm) | Devices[1] per Reel | Reel Size (inch) | Device Suffix |
|---|---|---|---|---|
| SO–8, SOP–8 | 12 | 2,500 | 13 | R2 |
| SO–14 | 16 | 2,500 | 13 | R2 |
| SO–16 | 16 | 2,500 | 13 | R2 |
| SO–16L, SO–8+8L WIDE | 16 | 1,000 | 13 | R2 |
| SO–20L WIDE | 24 | 1,000 | 13 | R2 |
| SO–24L WIDE | 24 | 1,000 | 13 | R2 |
| SO–28L WIDE | 24 | 1,000 | 13 | R2 |
| SO–28L WIDE | 32 | 1,000 | 13 | R3 |
| Micro–8 | 12 | 2,500 | 13 | R2 |
| PLCC–20 | 16 | 1,000 | 13 | R2 |
| PLCC–28 | 24 | 500 | 13 | R2 |
| PLCC–44 | 32 | 500 | 13 | R2 |
| PLCC–52 | 32 | 500 | 13 | R2 |
| PLCC–68 | 44 | 250 | 13 | R2 |
| PLCC–84 | 44 | 250 | 13 | R2 |
| TO–226AA (TO–92)[2] | 18 | 2,000 | 13 | RA, RE, RP, or RM (Ammo Pack) only |
| DPAK | 16 | 2,500 | 13 | RK |
| $D^2PAK$ | 24 | 800 | 13 | R4 |
| SOT–23 (5 Pin) | 8 | 3,000 | 7 | TR |
| SOT–89 (3/5 Pin) | 12 | 1,000 | 7 | T1 |

(1) Minimum order quantity is 1 reel. Distributors/OEM customers may break lots or reels at their option, however broken reels may not be returned.
(2) Integrated circuits in TO–226AA packages are available in Styes A and E only, with optional "Ammo Pack" (Suffix RP or RM). The RA and RP configurations are preferred. For ordering information please contact your local Motorola Semiconductor Sales Office.

# Analog MPQ Table

## Tape/Reel and Ammo Pack

| Package Type | Package Code | MPQ |
|---|---|---|
| **PLCC** | | |
| Case 775 | 0802 | 1000/reel |
| Case 776 | 0804 | 500/reel |
| Case 777 | 0801 | 500/reel |
| **SOIC** | | |
| Case 751 | 0095 | 2500/reel |
| Case 751A | 0096 | 2500/reel |
| Case 751B | 0097 | 2500/reel |
| Case 751G | 2003 | 1000/reel |
| Case 751D | 2005 | 1000/reel |
| Case 751E | 2008 | 1000/reel |
| Case 751F | 2009 | 1000/reel |
| **Micro–8** | | |
| Case 846A | – | 2500/reel |
| **TO–92** | | |
| Case 29 | 0031 | 2000/reel |
| Case 29 | 0031 | 2000/Ammo Pack |
| **DPAK** | | |
| Case 369A | – | 2500/reel |
| **$D^2PAK$** | | |
| Case 936 | – | 800/reel |
| **SOT–23 (5 Pin)** | | |
| Case 1212 | – | 3000/reel |
| **SOT–89 (3 Pin)** | | |
| Case 1213 | – | 1000/reel |
| **SOT–89 (5 Pin)** | | |
| Case 1214 | – | 1000/reel |

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# Packaging Information

## In Brief . . .

*The packaging availability for each device type is indicated on the individual data sheets and the Selector Guide. All of the outline dimensions for the packages are given in this section.*

*The maximum power consumption an integrated circuit can tolerate at a given operating ambient temperature can be found from the equation:*

$$P_{D(TA)} = \frac{T_{J(max)} - T_A}{R_{\theta JA(Typ)}}$$

*where:*

$P_{D(TA)}$ = *Power Dissipation allowable at a given operating ambient temperature. This must be greater than the sum of the products of the supply voltages and supply currents at the worst case operating condition.*

$T_{J(max)}$ = *Maximum operating Junction Temperature as listed in the Maximum Ratings Section. See individual data sheets for $T_{J(max)}$ information.*

$T_A$ = *Maximum desired operating Ambient Temperature*

$R_{\theta JA(Typ)}$ = *Typical Thermal Resistance Junction-to-Ambient*

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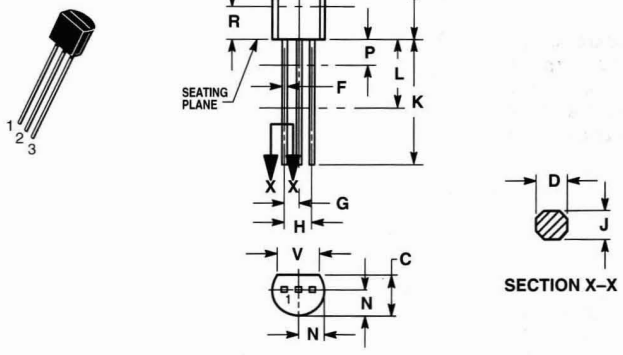
# Case Outline Dimensions

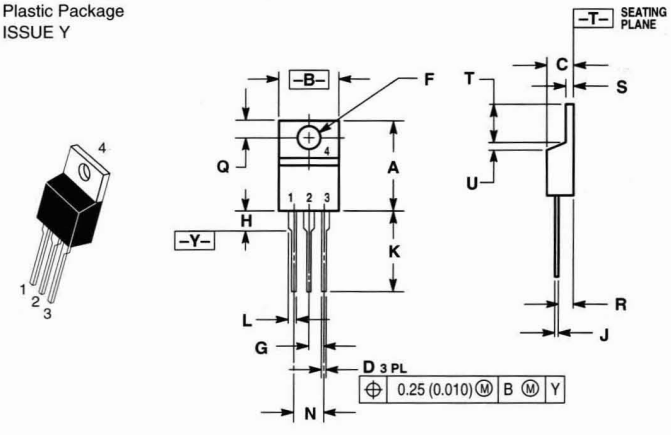
**LP, P, Z SUFFIX**
**CASE 29-04**
Plastic Package
(TO-226AA/TO-92)
ISSUE AD




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. CONTOUR OF PACKAGE BEYOND DIMENSION R IS UNCONTROLLED.
4. DIMENSION F APPLIES BETWEEN P AND L. DIMENSION D AND J APPLY BETWEEN L AND K MINIMUM. LEAD DIMENSION IS UNCONTROLLED IN P AND BEYOND DIMENSION K MINIMUM.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.175 | 0.205 | 4.45 | 5.20 |
| B | 0.170 | 0.210 | 4.32 | 5.33 |
| C | 0.125 | 0.165 | 3.18 | 4.19 |
| D | 0.016 | 0.022 | 0.41 | 0.55 |
| F | 0.016 | 0.019 | 0.41 | 0.48 |
| G | 0.045 | 0.055 | 1.15 | 1.39 |
| H | 0.095 | 0.105 | 2.42 | 2.66 |
| J | 0.015 | 0.020 | 0.39 | 0.50 |
| K | 0.500 | — | 12.70 | — |
| L | 0.250 | — | 6.35 | — |
| N | 0.080 | 0.105 | 2.04 | 2.66 |
| P | — | 0.100 | — | 2.54 |
| R | 0.115 | — | 2.93 | — |
| V | 0.135 | — | 3.43 | — |

**KC, T SUFFIX**
**CASE 221A-06**
Plastic Package
ISSUE Y




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.560 | 0.625 | 14.23 | 15.87 |
| B | 0.380 | 0.420 | 9.66 | 10.66 |
| C | 0.140 | 0.190 | 3.56 | 4.82 |
| D | 0.020 | 0.045 | 0.51 | 1.14 |
| F | 0.139 | 0.155 | 3.53 | 3.93 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | — | 0.280 | — | 7.11 |
| J | 0.012 | 0.045 | 0.31 | 1.14 |
| K | 0.500 | 0.580 | 12.70 | 14.73 |
| L | 0.045 | 0.070 | 1.15 | 1.77 |
| N | 0.200 BSC | | 5.08 BSC | |
| Q | 0.100 | 0.135 | 2.54 | 3.42 |
| R | 0.080 | 0.115 | 2.04 | 2.92 |
| S | 0.020 | 0.055 | 0.51 | 1.39 |
| T | 0.235 | 0.255 | 5.97 | 6.47 |
| U | 0.000 | 0.050 | 0.00 | 1.27 |

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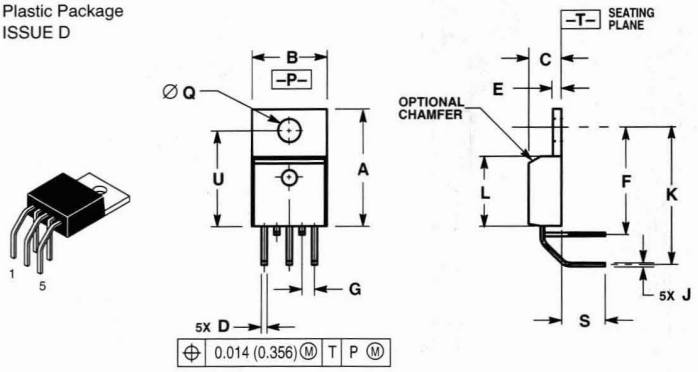
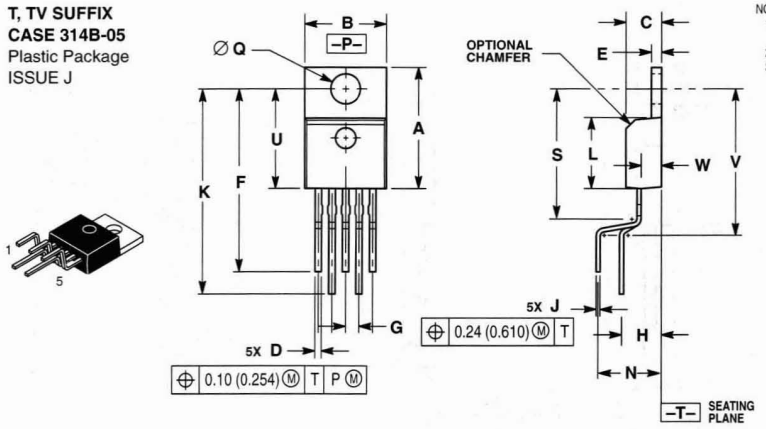
**TH SUFFIX**
**CASE 314A-03**
Plastic Package
ISSUE D




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 0.043 (1.092) MAXIMUM.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.572 | 0.613 | 14.529 | 15.570 |
| B | 0.390 | 0.415 | 9.906 | 10.541 |
| C | 0.170 | 0.180 | 4.318 | 4.572 |
| D | 0.025 | 0.038 | 0.635 | 0.965 |
| E | 0.048 | 0.055 | 1.219 | 1.397 |
| F | 0.570 | 0.585 | 14.478 | 14.859 |
| G | 0.067 BSC | | 1.702 BSC | |
| J | 0.015 | 0.025 | 0.381 | 0.635 |
| K | 0.730 | 0.745 | 18.542 | 18.923 |
| L | 0.320 | 0.365 | 8.128 | 9.271 |
| Q | 0.140 | 0.153 | 3.556 | 3.886 |
| S | 0.210 | 0.260 | 5.334 | 6.604 |
| U | 0.468 | 0.505 | 11.888 | 12.827 |

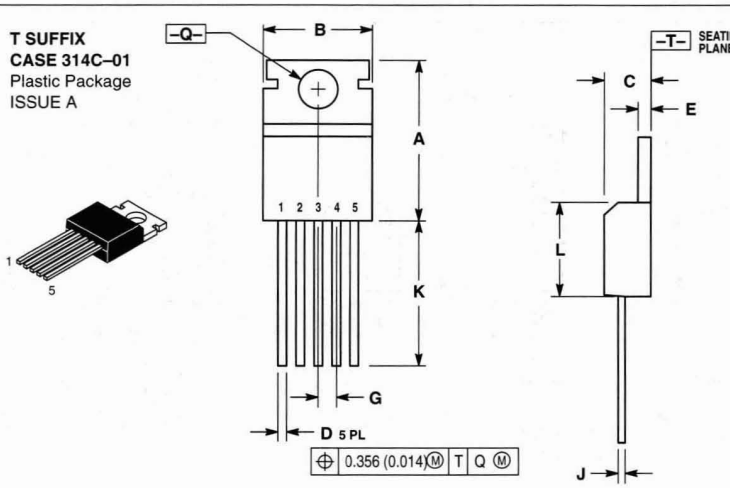
**T, TV SUFFIX**
**CASE 314B-05**
Plastic Package
ISSUE J




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 0.043 (1.092) MAXIMUM.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.572 | 0.613 | 14.529 | 15.570 |
| B | 0.390 | 0.415 | 9.906 | 10.541 |
| C | 0.170 | 0.180 | 4.318 | 4.572 |
| D | 0.025 | 0.038 | 0.635 | 0.965 |
| E | 0.048 | 0.055 | 1.219 | 1.397 |
| F | 0.850 | 0.935 | 21.590 | 23.749 |
| G | 0.067 BSC | | 1.702 BSC | |
| H | 0.166 BSC | | 4.216 BSC | |
| J | 0.015 | 0.025 | 0.381 | 0.635 |
| K | 0.900 | 1.100 | 22.860 | 27.940 |
| L | 0.320 | 0.365 | 8.128 | 9.271 |
| N | 0.320 BSC | | 8.128 BSC | |
| Q | 0.140 | 0.153 | 3.556 | 3.886 |
| S | — | 0.620 | — | 15.748 |
| U | 0.468 | 0.505 | 11.888 | 12.827 |
| V | — | 0.735 | — | 18.669 |
| W | 0.090 | 0.110 | 2.286 | 2.794 |

**T SUFFIX**
**CASE 314C–01**
Plastic Package
ISSUE A



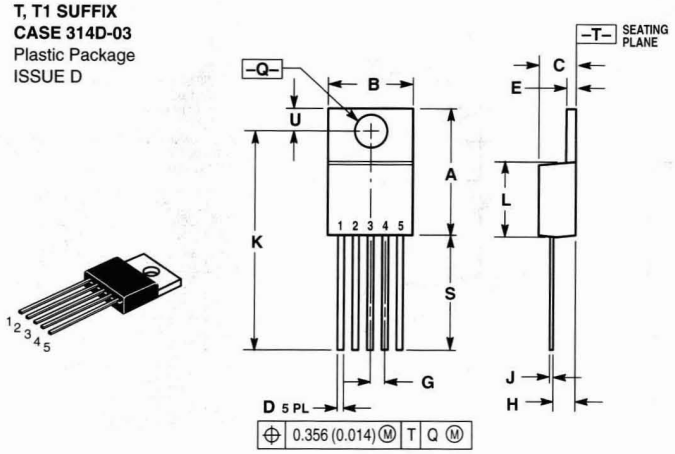

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 10.92 (0.043) MAXIMUM.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.610 | 0.625 | 15.59 | 15.88 |
| B | 0.380 | 0.420 | 9.65 | 10.67 |
| C | 0.160 | 0.190 | 4.06 | 4.83 |
| D | 0.020 | 0.040 | 0.51 | 1.02 |
| E | 0.035 | 0.055 | 0.89 | 1.40 |
| G | 0.067 BSC | | 1.702 BSC | |
| J | 0.015 | 0.025 | 0.38 | 0.64 |
| K | 0.500 | — | 12.70 | — |
| L | 0.355 | 0.370 | 9.02 | 9.40 |
| Q | 0.139 | 0.147 | 3.53 | 3.73 |

13

**T, T1 SUFFIX**
**CASE 314D-03**
Plastic Package
ISSUE D

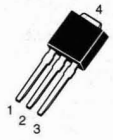


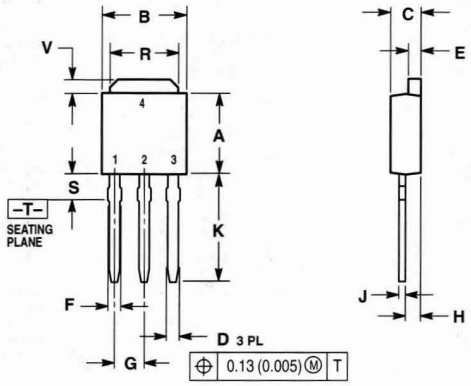



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 10.92 (0.043) MAXIMUM.

| DIM | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 0.572 | 0.613 | 14.529 | 15.570 |
| B | 0.390 | 0.415 | 9.906 | 10.541 |
| C | 0.170 | 0.180 | 4.318 | 4.572 |
| D | 0.025 | 0.038 | 0.635 | 0.965 |
| E | 0.048 | 0.055 | 1.219 | 1.397 |
| G | 0.067 BSC | | 1.702 BSC | |
| H | 0.087 | 0.112 | 2.210 | 2.845 |
| J | 0.015 | 0.025 | 0.381 | 0.635 |
| K | 1.020 | 1.065 | 25.908 | 27.051 |
| L | 0.320 | 0.365 | 8.128 | 9.271 |
| Q | 0.140 | 0.153 | 3.556 | 3.886 |
| U | 0.105 | 0.117 | 2.667 | 2.972 |
| S | 0.543 | 0.582 | 13.792 | 14.783 |

**DT-1 SUFFIX**
**CASE 369-07**
Plastic Package
(DPAK)
ISSUE K

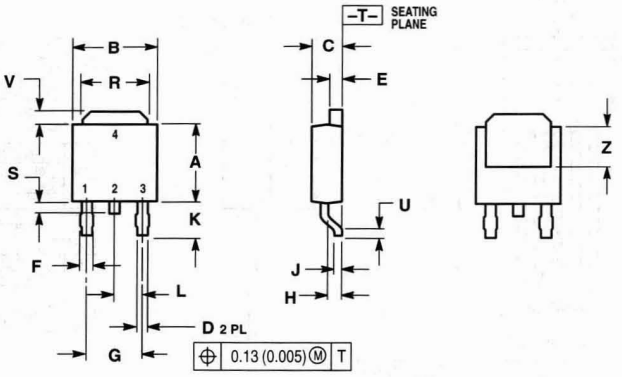





NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

| DIM | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 0.235 | 0.250 | 5.97 | 6.35 |
| B | 0.250 | 0.265 | 6.35 | 6.73 |
| C | 0.086 | 0.094 | 2.19 | 2.38 |
| D | 0.027 | 0.035 | 0.69 | 0.88 |
| E | 0.033 | 0.040 | 0.84 | 1.01 |
| F | 0.037 | 0.047 | 0.94 | 1.19 |
| G | 0.090 BSC | | 2.29 BSC | |
| H | 0.034 | 0.040 | 0.87 | 1.01 |
| J | 0.018 | 0.023 | 0.46 | 0.58 |
| K | 0.350 | 0.380 | 8.89 | 9.65 |
| R | 0.175 | 0.215 | 4.45 | 5.46 |
| S | 0.050 | 0.090 | 1.27 | 2.28 |
| V | 0.030 | 0.050 | 0.77 | 1.27 |

**DT SUFFIX**
**CASE 369A-13**
Plastic Package
(DPAK)
ISSUE Y

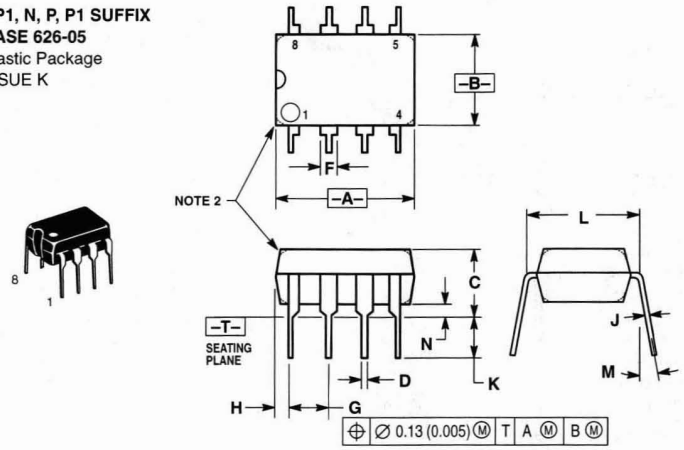



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

| DIM | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 0.235 | 0.250 | 5.97 | 6.35 |
| B | 0.250 | 0.265 | 6.35 | 6.73 |
| C | 0.086 | 0.094 | 2.19 | 2.38 |
| D | 0.027 | 0.035 | 0.69 | 0.88 |
| E | 0.033 | 0.040 | 0.84 | 1.01 |
| F | 0.037 | 0.047 | 0.94 | 1.19 |
| G | 0.180 BSC | | 4.58 BSC | |
| H | 0.034 | 0.040 | 0.87 | 1.01 |
| J | 0.018 | 0.023 | 0.46 | 0.58 |
| K | 0.102 | 0.114 | 2.60 | 2.89 |
| L | 0.090 BSC | | 2.29 BSC | |
| R | 0.175 | 0.215 | 4.45 | 5.46 |
| S | 0.020 | 0.050 | 0.51 | 1.27 |
| U | 0.020 | — | 0.51 | — |
| V | 0.030 | 0.050 | 0.77 | 1.27 |
| Z | 0.138 | — | 3.51 | — |

13

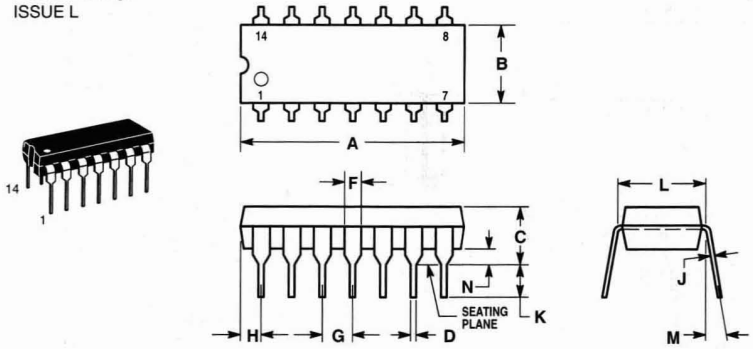
**DP1, N, P, P1 SUFFIX**
**CASE 626-05**
Plastic Package
ISSUE K




NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.40 | 10.16 | 0.370 | 0.400 |
| B | 6.10 | 6.60 | 0.240 | 0.260 |
| C | 3.94 | 4.45 | 0.155 | 0.175 |
| D | 0.38 | 0.51 | 0.015 | 0.020 |
| F | 1.02 | 1.78 | 0.040 | 0.070 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.76 | 1.27 | 0.030 | 0.050 |
| J | 0.20 | 0.30 | 0.008 | 0.012 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 7.62 BSC | | 0.300 BSC | |
| M | — | 10° | — | 10° |
| N | 0.76 | 1.01 | 0.030 | 0.040 |

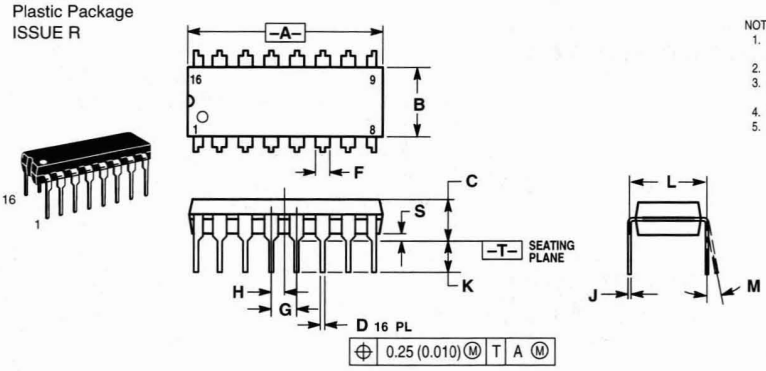
**N, P, N-14, P2 SUFFIX**
**CASE 646-06**
Plastic Package
ISSUE L




NOTES:
1. LEADS WITHIN 0.13 (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
4. ROUNDED CORNERS OPTIONAL.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.715 | 0.770 | 18.16 | 19.56 |
| B | 0.240 | 0.260 | 6.10 | 6.60 |
| C | 0.145 | 0.185 | 3.69 | 4.69 |
| D | 0.015 | 0.021 | 0.38 | 0.53 |
| F | 0.040 | 0.070 | 1.02 | 1.78 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | 0.052 | 0.095 | 1.32 | 2.41 |
| J | 0.008 | 0.015 | 0.20 | 0.38 |
| K | 0.115 | 0.135 | 2.92 | 3.43 |
| L | 0.300 BSC | | 7.62 BSC | |
| M | 0° | 10° | 0° | 10° |
| N | 0.015 | 0.039 | 0.39 | 1.01 |

**DP2, N, P, PC SUFFIX**
**CASE 648-08**
Plastic Package
ISSUE R

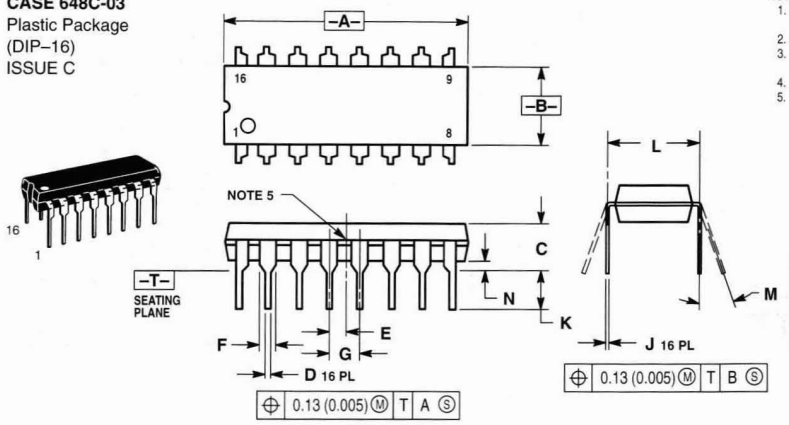



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.740 | 0.770 | 18.80 | 19.55 |
| B | 0.250 | 0.270 | 6.35 | 6.85 |
| C | 0.145 | 0.175 | 3.69 | 4.44 |
| D | 0.015 | 0.021 | 0.39 | 0.53 |
| F | 0.040 | 0.70 | 1.02 | 1.77 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | 0.050 BSC | | 1.27 BSC | |
| J | 0.008 | 0.015 | 0.21 | 0.38 |
| K | 0.110 | 0.130 | 2.80 | 3.30 |
| L | 0.295 | 0.305 | 7.50 | 7.74 |
| M | 0° | 10° | 0° | 10° |
| S | 0.020 | 0.040 | 0.51 | 1.01 |

13

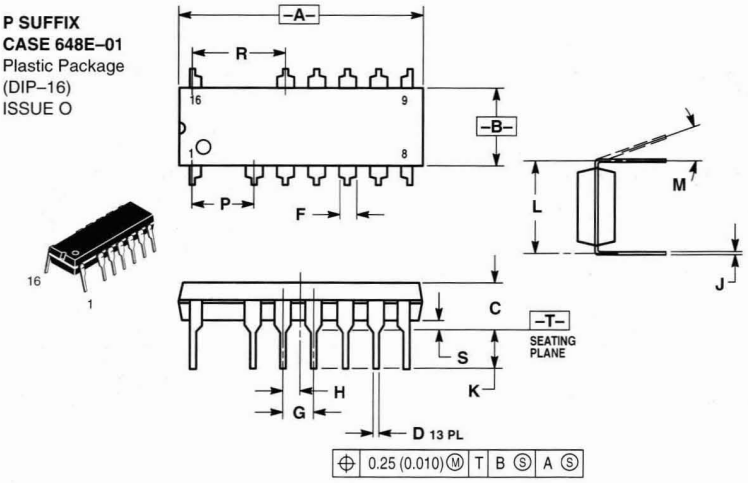
**B, P, P2, V SUFFIX**
**CASE 648C-03**
Plastic Package
(DIP–16)
ISSUE C




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. INTERNAL LEAD CONNECTION BETWEEN 4 AND 5, 12 AND 13.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.740 | 0.840 | 18.80 | 21.34 |
| B | 0.240 | 0.260 | 6.10 | 6.60 |
| C | 0.145 | 0.185 | 3.69 | 4.69 |
| D | 0.015 | 0.021 | 0.38 | 0.53 |
| E | 0.050 BSC | | 1.27 BSC | |
| F | 0.040 | 0.70 | 1.02 | 1.78 |
| G | 0.100 BSC | | 2.54 BSC | |
| J | 0.008 | 0.015 | 0.20 | 0.38 |
| K | 0.115 | 0.135 | 2.92 | 3.43 |
| L | 0.300 BSC | | 7.62 BSC | |
| M | 0° | 10° | 0° | 10° |
| N | 0.015 | 0.040 | 0.39 | 1.01 |

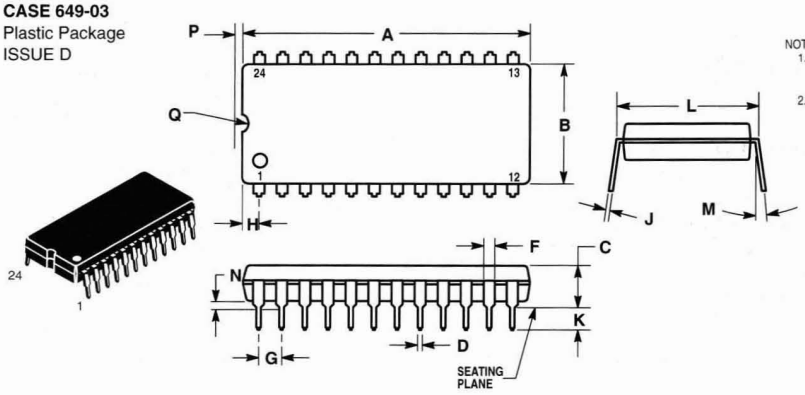
**P SUFFIX**
**CASE 648E–01**
Plastic Package
(DIP–16)
ISSUE O




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION A AND B DOES NOT INCLUDE MOLD PROTRUSION.
5. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.25 (0.010).
6. ROUNDED CORNER OPTIONAL.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.740 | 0.760 | 18.80 | 19.30 |
| B | 0.245 | 0.260 | 6.23 | 6.60 |
| C | 0.145 | 0.175 | 3.69 | 4.44 |
| D | 0.015 | 0.021 | 0.39 | 0.53 |
| F | 0.050 | 0.070 | 1.27 | 1.77 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | 0.050 BSC | | 1.27 BSC | |
| J | 0.008 | 0.015 | 0.21 | 0.38 |
| K | 0.120 | 0.140 | 3.05 | 3.55 |
| L | 0.295 | 0.305 | 7.50 | 7.74 |
| M | 0° | 10° | 0° | 10° |
| P | 0.200 BSC | | 5.08 BSC | |
| R | 0.300 BSC | | 7.62 BSC | |
| S | 0.015 | 0.035 | 0.39 | 0.88 |

**P SUFFIX**
**CASE 649-03**
Plastic Package
ISSUE D

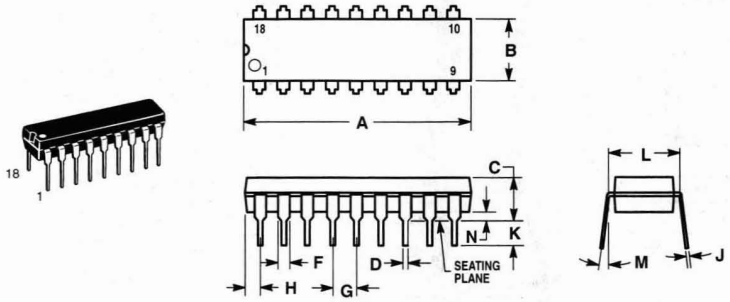



NOTES:
1. LEADS WITHIN 0.13 (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 31.50 | 32.13 | 1.240 | 1.265 |
| B | 13.21 | 13.72 | 0.520 | 0.540 |
| C | 4.70 | 5.21 | 0.185 | 0.205 |
| D | 0.38 | 0.51 | 0.015 | 0.020 |
| F | 1.02 | 1.52 | 0.040 | 0.060 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.65 | 2.16 | 0.065 | 0.085 |
| J | 0.20 | 0.30 | 0.008 | 0.012 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 14.99 | 15.49 | 0.590 | 0.610 |
| M | — | 10 | — | 10° |
| N | 0.51 | 1.02 | 0.020 | 0.040 |
| P | 0.13 | 0.38 | 0.005 | 0.015 |
| Q | 0.51 | 0.76 | 0.020 | 0.030 |

13

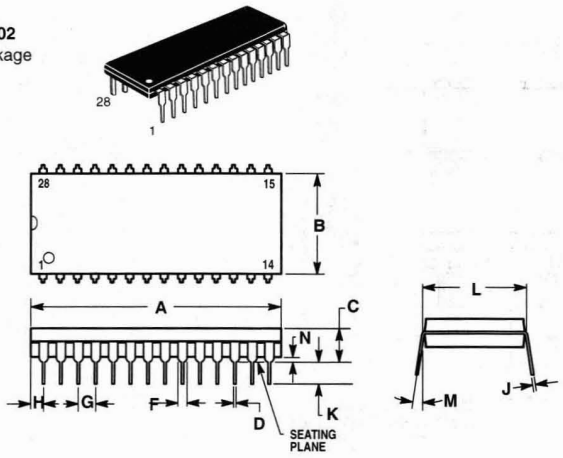
**A, B, N, P SUFFIX**
**CASE 707-02**
Plastic Package
ISSUE C




NOTES:
1. POSITIONAL TOLERANCE OF LEADS (D), SHALL BE WITHIN 0.25 (0.010) AT MAXIMUM MATERIAL CONDITION, IN RELATION TO SEATING PLANE AND EACH OTHER.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 22.22 | 23.24 | 0.875 | 0.915 |
| B | 6.10 | 6.60 | 0.240 | 0.260 |
| C | 3.56 | 4.57 | 0.140 | 0.180 |
| D | 0.36 | 0.56 | 0.014 | 0.022 |
| F | 1.27 | 1.78 | 0.050 | 0.070 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.02 | 1.52 | 0.040 | 0.060 |
| J | 0.20 | 0.30 | 0.008 | 0.012 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 7.62 BSC | | 0.300 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.51 | 1.02 | 0.020 | 0.040 |

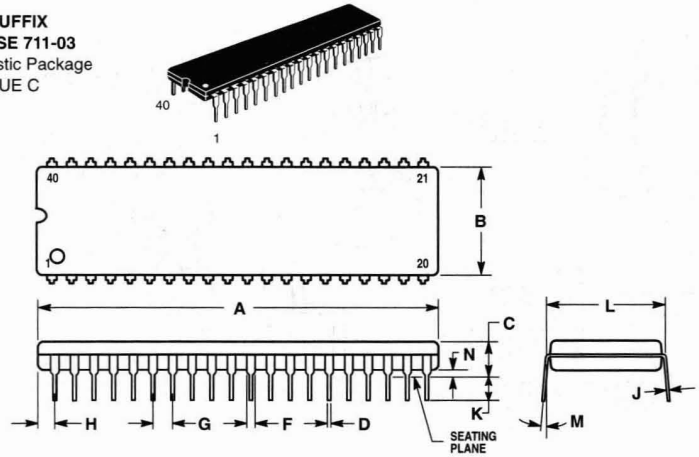
**P SUFFIX**
**CASE 710-02**
Plastic Package
ISSUE B




NOTES:
1. POSITIONAL TOLERANCE OF LEADS (D), SHALL BE WITHIN 0.25 (0.010) AT MAXIMUM MATERIAL CONDITION, IN RELATION TO SEATING PLANE AND EACH OTHER.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 36.45 | 37.21 | 1.435 | 1.465 |
| B | 13.72 | 14.22 | 0.540 | 0.560 |
| C | 3.94 | 5.08 | 0.155 | 0.200 |
| D | 0.36 | 0.56 | 0.014 | 0.022 |
| F | 1.02 | 1.52 | 0.040 | 0.060 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.65 | 2.16 | 0.065 | 0.085 |
| J | 0.20 | 0.38 | 0.008 | 0.015 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 15.24 BSC | | 0.600 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.51 | 1.02 | 0.020 | 0.040 |

**P SUFFIX**
**CASE 711-03**
Plastic Package
ISSUE C

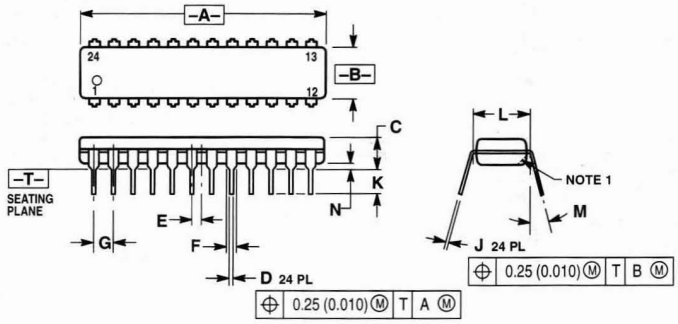



NOTES:
1. POSITIONAL TOLERANCE OF LEADS (D), SHALL BE WITHIN 0.25 (0.010) AT MAXIMUM MATERIAL CONDITION, IN RELATION TO SEATING PLANE AND EACH OTHER.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 51.69 | 52.45 | 2.035 | 2.065 |
| B | 13.72 | 14.22 | 0.540 | 0.560 |
| C | 3.94 | 5.08 | 0.155 | 0.200 |
| D | 0.36 | 0.56 | 0.014 | 0.022 |
| F | 1.02 | 1.52 | 0.040 | 0.060 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.65 | 2.16 | 0.065 | 0.085 |
| J | 0.20 | 0.38 | 0.008 | 0.015 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 15.24 BSC | | 0.600 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.51 | 1.02 | 0.020 | 0.040 |

13

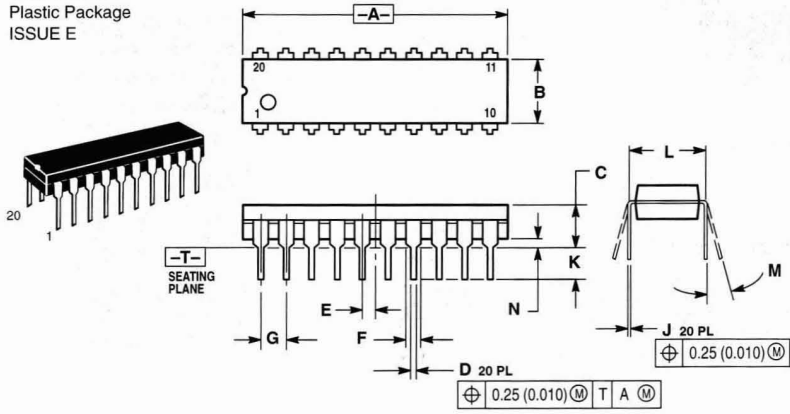
**F, P, P-3 SUFFIX**
**CASE 724-03**
Plastic Package
(NDIP–24)
ISSUE D




NOTES:
1. CHAMFERED CONTOUR OPTIONAL.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
4. CONTROLLING DIMENSION: INCH.

| DIM | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 1.230 | 1.265 | 31.25 | 32.13 |
| B | 0.250 | 0.270 | 6.35 | 6.85 |
| C | 0.145 | 0.175 | 3.69 | 4.44 |
| D | 0.015 | 0.020 | 0.38 | 0.51 |
| E | 0.050 BSC | | 1.27 BSC | |
| F | 0.040 | 0.060 | 1.02 | 1.52 |
| G | 0.100 BSC | | 2.54 BSC | |
| J | 0.007 | 0.012 | 0.18 | 0.30 |
| K | 0.110 | 0.140 | 2.80 | 3.55 |
| L | 0.300 BSC | | 7.62 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.020 | 0.040 | 0.51 | 1.01 |

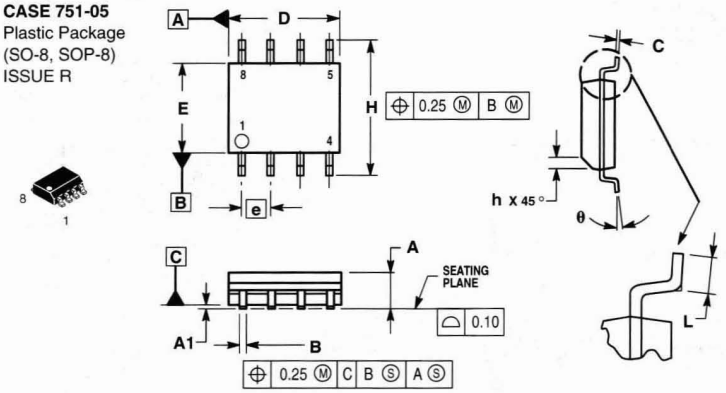
**H, P, DP SUFFIX**
**CASE 738-03**
Plastic Package
ISSUE E




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

| DIM | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 1.010 | 1.070 | 25.66 | 27.17 |
| B | 0.240 | 0.260 | 6.10 | 6.60 |
| C | 0.150 | 0.180 | 3.81 | 4.57 |
| D | 0.015 | 0.022 | 0.39 | 0.55 |
| E | 0.050 BSC | | 1.27 BSC | |
| F | 0.050 | 0.070 | 1.27 | 1.77 |
| G | 0.100 BSC | | 2.54 BSC | |
| J | 0.008 | 0.015 | 0.21 | 0.38 |
| K | 0.110 | 0.140 | 2.80 | 3.55 |
| L | 0.300 BSC | | 7.62 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.020 | 0.040 | 0.51 | 1.01 |

**D, D1, D2 SUFFIX**
**CASE 751-05**
Plastic Package
(SO-8, SOP-8)
ISSUE R





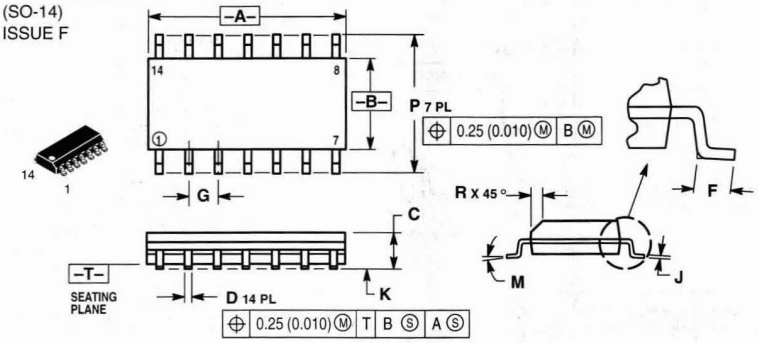


NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. DIMENSIONS ARE IN MILLIMETERS.
3. DIMENSION D AND E DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.
5. DIMENSION B DOES NOT INCLUDE MOLD PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 TOTAL IN EXCESS OF THE B DIMENSION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS | |
|---|---|---|
| | MIN | MAX |
| A | 1.35 | 1.75 |
| A1 | 0.10 | 0.25 |
| B | 0.35 | 0.49 |
| C | 0.18 | 0.25 |
| D | 4.80 | 5.00 |
| E | 3.80 | 4.00 |
| e | 1.27 BSC | |
| H | 5.80 | 6.20 |
| h | 0.25 | 0.50 |
| L | 0.40 | 1.25 |
| θ | 0° | 7° |

13

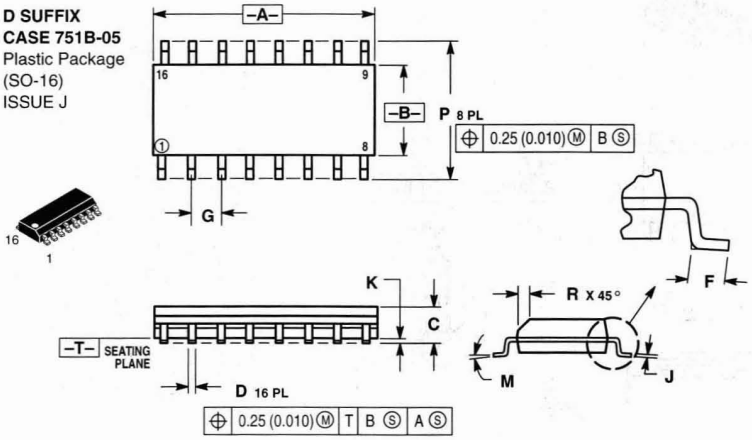
**D SUFFIX**
**CASE 751A-03**
Plastic Package
(SO-14)
ISSUE F




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 8.55 | 8.75 | 0.337 | 0.344 |
| B | 3.80 | 4.00 | 0.150 | 0.157 |
| C | 1.35 | 1.75 | 0.054 | 0.068 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.40 | 1.25 | 0.016 | 0.049 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.19 | 0.25 | 0.008 | 0.009 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 5.80 | 6.20 | 0.228 | 0.244 |
| R | 0.25 | 0.50 | 0.010 | 0.019 |

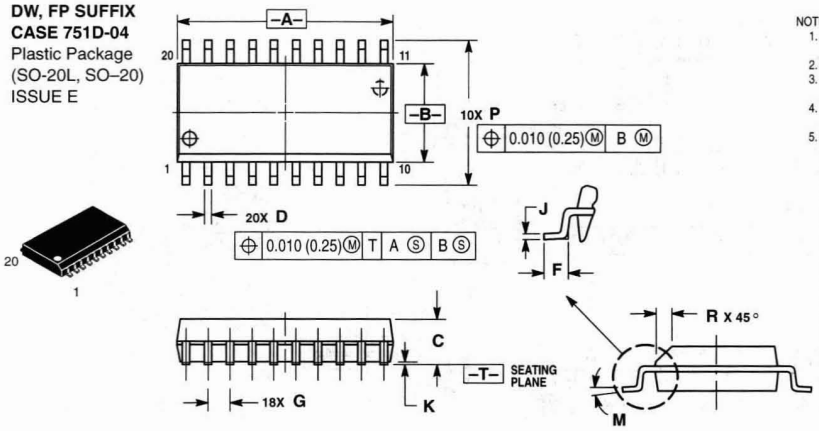
**D SUFFIX**
**CASE 751B-05**
Plastic Package
(SO-16)
ISSUE J




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.80 | 10.00 | 0.386 | 0.393 |
| B | 3.80 | 4.00 | 0.150 | 0.157 |
| C | 1.35 | 1.75 | 0.054 | 0.068 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.40 | 1.25 | 0.016 | 0.049 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.19 | 0.25 | 0.008 | 0.009 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 5.80 | 6.20 | 0.229 | 0.244 |
| R | 0.25 | 0.50 | 0.010 | 0.019 |

**DW, FP SUFFIX**
**CASE 751D-04**
Plastic Package
(SO-20L, SO–20)
ISSUE E

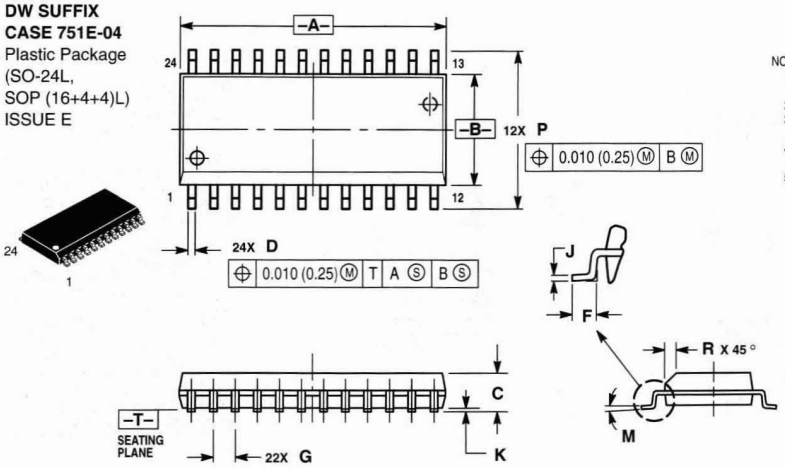



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.150 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 12.65 | 12.95 | 0.499 | 0.510 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.50 | 0.90 | 0.020 | 0.035 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.25 | 0.32 | 0.010 | 0.012 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 10.05 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |

13

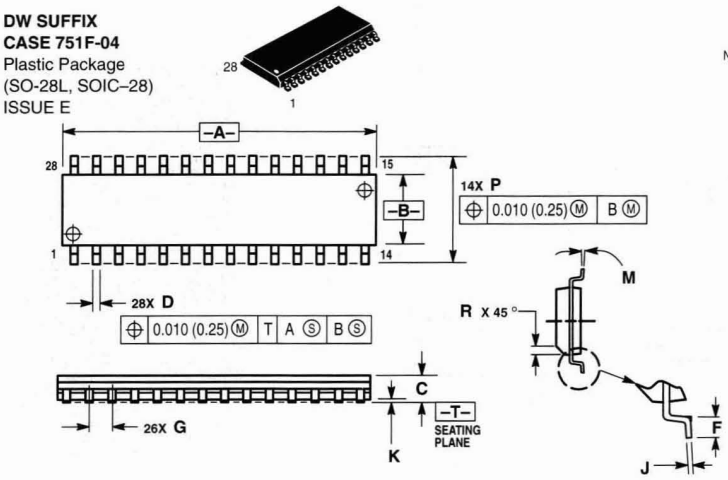
**DW SUFFIX**
**CASE 751E-04**
Plastic Package
(SO-24L,
SOP (16+4+4)L)
ISSUE E




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 15.25 | 15.54 | 0.601 | 0.612 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.41 | 0.90 | 0.016 | 0.035 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.23 | 0.32 | 0.009 | 0.013 |
| K | 0.13 | 0.29 | 0.005 | 0.011 |
| M | 0° | 8° | 0° | 8° |
| P | 10.05 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |

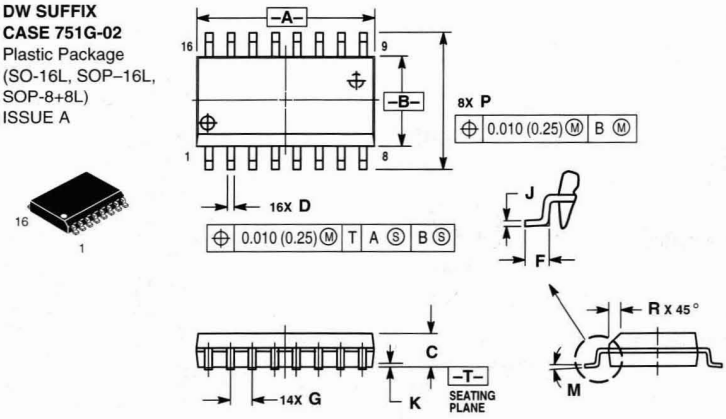
**DW SUFFIX**
**CASE 751F-04**
Plastic Package
(SO-28L, SOIC–28)
ISSUE E




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 17.80 | 18.05 | 0.701 | 0.711 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.41 | 0.90 | 0.016 | 0.035 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.23 | 0.32 | 0.009 | 0.013 |
| K | 0.13 | 0.29 | 0.005 | 0.011 |
| M | 0° | 8° | 0° | 8° |
| P | 10.01 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |

**DW SUFFIX**
**CASE 751G-02**
Plastic Package
(SO-16L, SOP–16L,
SOP-8+8L)
ISSUE A

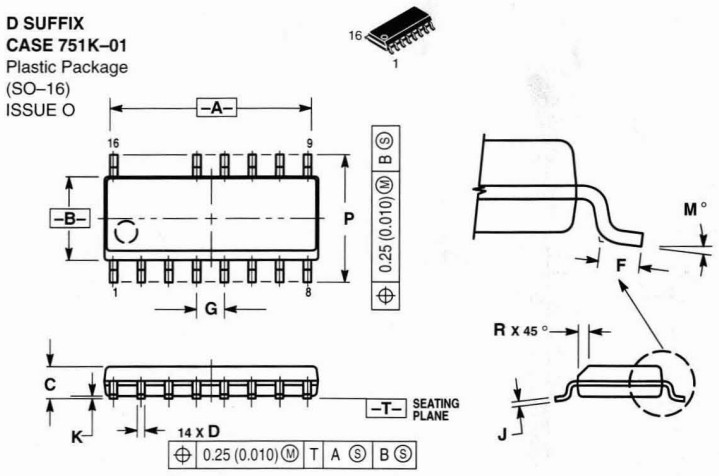



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 10.15 | 10.45 | 0.400 | 0.411 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.50 | 0.90 | 0.020 | 0.035 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.25 | 0.32 | 0.010 | 0.012 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 10.05 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |

13

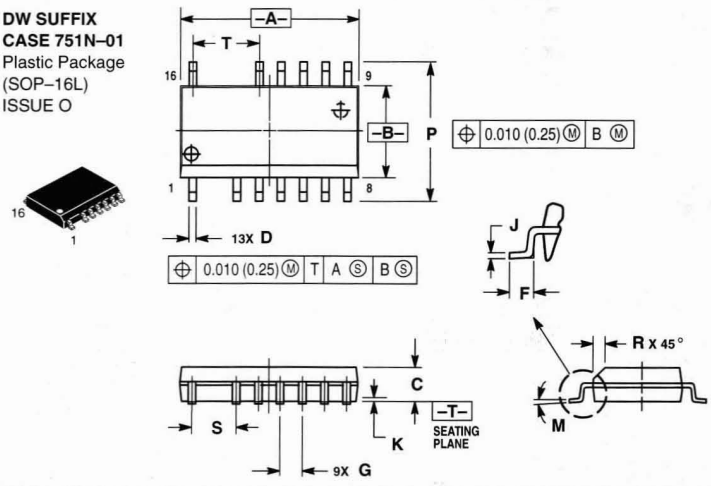
**D SUFFIX**
**CASE 751K–01**
Plastic Package
(SO–16)
ISSUE O




NOTES:
1 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION: MILLIMETER.
3 DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4 MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5 DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.80 | 10.00 | 0.368 | 0.393 |
| B | 3.80 | 4.00 | 0.150 | 0.157 |
| C | 1.35 | 1.75 | 0.054 | 0.068 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.40 | 1.25 | 0.016 | 0.049 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.19 | 0.25 | 0.008 | 0.009 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 5.80 | 6.20 | 0.229 | 0.244 |
| R | 0.25 | 0.50 | 0.010 | 0.019 |

**DW SUFFIX**
**CASE 751N–01**
Plastic Package
(SOP–16L)
ISSUE O

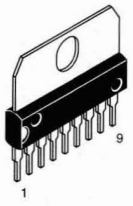


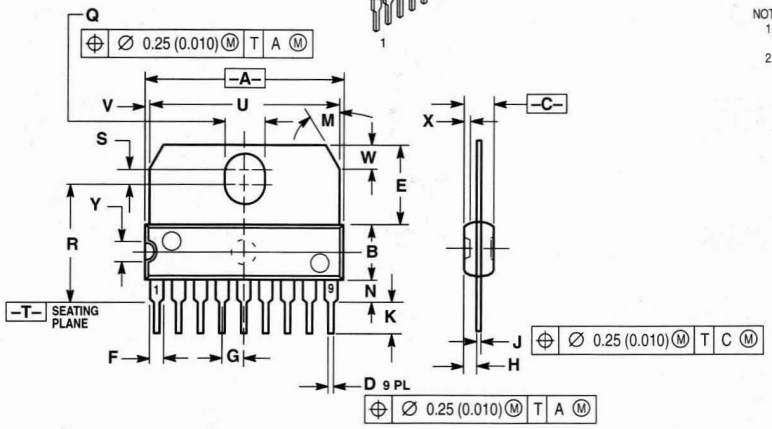

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 10.15 | 10.45 | 0.400 | 0.411 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.50 | 0.90 | 0.020 | 0.035 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.25 | 0.32 | 0.010 | 0.012 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0° | 7° | 0° | 7° |
| P | 10.05 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |
| S | 2.54 BSC | | 0.100 BSC | |
| T | 3.81 BSC | | 0.150 BSC | |

13

**CASE 762-01**
Plastic Medium Power Package
(SIP-9)
ISSUE C

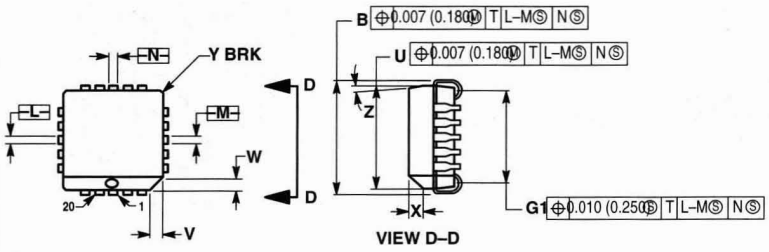




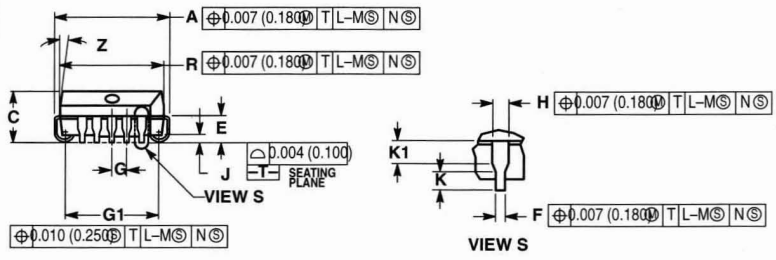

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 22.40 | 23.00 | 0.873 | 0.897 |
| B | 6.40 | 6.60 | 0.252 | 0.260 |
| C | 3.45 | 3.65 | 0.135 | 1.143 |
| D | 0.40 | 0.55 | 0.015 | 0.021 |
| E | 9.35 | 9.60 | 0.368 | 0.377 |
| F | 1.40 | 1.60 | 0.055 | 0.062 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.51 | 1.71 | 0.059 | 0.067 |
| J | 0.360 | 0.400 | 0.014 | 0.015 |
| K | 3.95 | 4.20 | 0.155 | 0.165 |
| M | 30° BSC | | 30° BSC | |
| N | 2.50 | 2.70 | 0.099 | 0.106 |
| Q | 3.15 | 3.45 | 0.124 | 0.135 |
| R | 13.60 | 13.90 | 0.535 | 0.547 |
| S | 1.65 | 1.95 | 0.064 | 0.076 |
| U | 22.00 | 22.20 | 0.866 | 0.874 |
| V | 0.55 | 0.75 | 0.021 | 0.029 |
| W | 2.89 BSC | | 0.113 BSC | |
| X | 0.65 | 0.75 | 0.025 | 0.029 |
| Y | 2.70 | 2.80 | 0.106 | 0.110 |

**FN SUFFIX**
**CASE 775-02**
Plastic Package
(PLCC-20)
ISSUE C



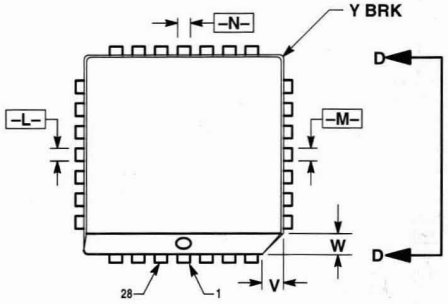

NOTES:
1. DATUMS –L–, –M–, AND –N– DETERMINED WHERE TOP OF LEAD SHOULDER EXITS PLASTIC BODY AT MOLD PARTING LINE.
2. DIMENSION G1, TRUE POSITION TO BE MEASURED AT DATUM –T–, SEATING PLANE.
3. DIMENSIONS R AND U DO NOT INCLUDE MOLD FLASH. ALLOWABLE MOLD FLASH IS 0.010 (0.250) PER SIDE.
4. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
5. CONTROLLING DIMENSION: INCH.
6. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM BY UP TO 0.012 (0.300). DIMENSIONS R AND U ARE DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTERLEAD FLASH, BUT INCLUDING ANY MISMATCH BETWEEN THE TOP AND BOTTOM OF THE PLASTIC BODY.
7. DIMENSION H DOES NOT INCLUDE DAMBAR PROTRUSION OR INTRUSION. THE DAMBAR PROTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE GREATER THAN 0.037 (0.940). THE DAMBAR INTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE SMALLER THAN 0.025 (0.635).

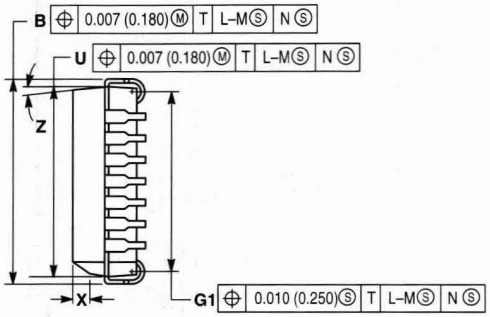

A ⊕ 0.007 (0.180) Ⓜ T L–M Ⓢ N Ⓢ
Z
R ⊕ 0.007 (0.180) Ⓜ T L–M Ⓢ N Ⓢ
C
E
G
J
⌓ 0.004 (0.100) –T– SEATING PLANE
VIEW S
G1
⊕ 0.010 (0.250) Ⓢ T L–M Ⓢ N Ⓢ
H ⊕ 0.007 (0.180) Ⓜ T L–M Ⓢ N Ⓢ
K1
K
F ⊕ 0.007 (0.180) Ⓜ T L–M Ⓢ N Ⓢ
VIEW S

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.385 | 0.395 | 9.78 | 10.03 |
| B | 0.385 | 0.395 | 9.78 | 10.03 |
| C | 0.165 | 0.180 | 4.20 | 4.57 |
| E | 0.090 | 0.110 | 2.29 | 2.79 |
| F | 0.013 | 0.019 | 0.33 | 0.48 |
| G | 0.050 BSC | | 1.27 BSC | |
| H | 0.026 | 0.032 | 0.66 | 0.81 |
| J | 0.020 | — | 0.51 | — |
| K | 0.025 | — | 0.64 | — |
| R | 0.350 | 0.356 | 8.89 | 9.04 |
| U | 0.350 | 0.356 | 8.89 | 9.04 |
| V | 0.042 | 0.048 | 1.07 | 1.21 |
| W | 0.042 | 0.048 | 1.07 | 1.21 |
| X | 0.042 | 0.056 | 1.07 | 1.42 |
| Y | — | 0.020 | — | 0.50 |
| Z | 2° | 10° | 2° | 10° |
| G1 | 0.310 | 0.330 | 7.88 | 8.38 |
| K1 | 0.040 | — | 1.02 | — |

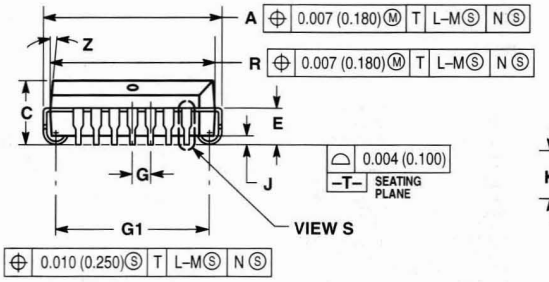
13

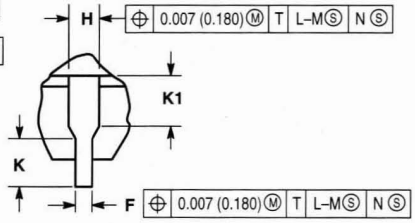
**FN SUFFIX**
**CASE 776-02**
Plastic Package
(PLCC–28)
ISSUE D




VIEW D–D



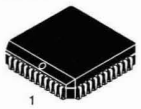

VIEW S

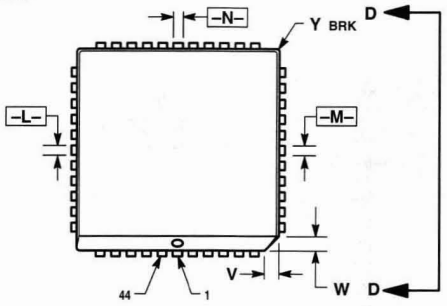
NOTES:
1. DATUMS –L–, –M–, AND –N– DETERMINED WHERE TOP OF LEAD SHOULDER EXITS PLASTIC BODY AT MOLD PARTING LINE.
2. DIMENSION G1, TRUE POSITION TO BE MEASURED AT DATUM –T–, SEATING PLANE.
3. DIMENSIONS R AND U DO NOT INCLUDE MOLD FLASH. ALLOWABLE MOLD FLASH IS 0.010 (0.250) PER SIDE.
4. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
5. CONTROLLING DIMENSION: INCH.
6. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM BY UP TO 0.012 (0.300). DIMENSIONS R AND U ARE DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTERLEAD FLASH, BUT INCLUDING ANY MISMATCH BETWEEN THE TOP AND BOTTOM OF THE PLASTIC BODY.
7. DIMENSION H DOES NOT INCLUDE DAMBAR PROTRUSION OR INTRUSION. THE DAMBAR PROTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE GREATER THAN 0.037 (0.940). THE DAMBAR INTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE SMALLER THAN 0.025 (0.635).

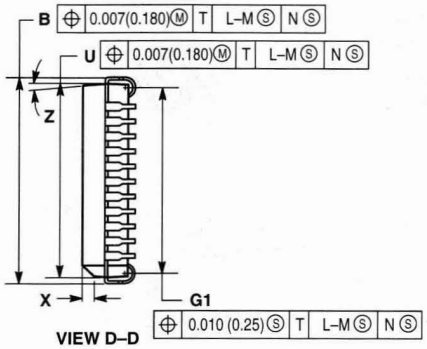
| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.485 | 0.495 | 12.32 | 12.57 |
| B | 0.485 | 0.495 | 12.32 | 12.57 |
| C | 0.165 | 0.180 | 4.20 | 4.57 |
| E | 0.090 | 0.110 | 2.29 | 2.79 |
| F | 0.013 | 0.019 | 0.33 | 0.48 |
| G | 0.050 BSC | | 1.27 BSC | |
| H | 0.026 | 0.032 | 0.66 | 0.81 |
| J | 0.020 | — | 0.51 | — |
| K | 0.025 | — | 0.64 | — |
| R | 0.450 | 0.456 | 11.43 | 11.58 |
| U | 0.450 | 0.456 | 11.43 | 11.58 |
| V | 0.042 | 0.048 | 1.07 | 1.21 |
| W | 0.042 | 0.048 | 1.07 | 1.21 |
| X | 0.042 | 0.056 | 1.07 | 1.42 |
| Y | — | 0.020 | — | 0.50 |
| Z | 2° | 10° | 2° | 10° |
| G1 | 0.410 | 0.430 | 10.42 | 10.92 |
| K1 | 0.040 | — | 1.02 | — |

13

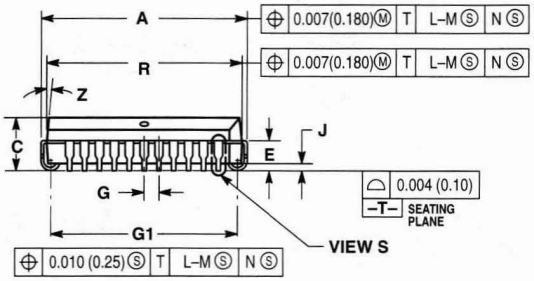
**FN SUFFIX**
**CASE 777-02**
Plastic Package
(PLCC)
ISSUE C

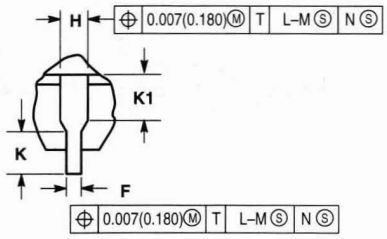





VIEW D–D



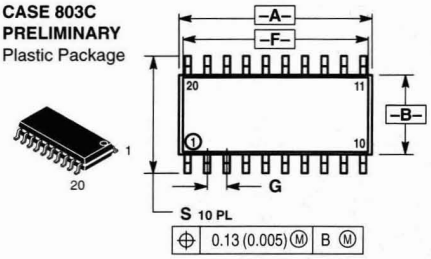




VIEW S

| DIM | INCHES MIN | INCHES MAX | MILLIMETERS MIN | MILLIMETERS MAX |
|---|---|---|---|---|
| A | 0.685 | 0.695 | 17.40 | 17.65 |
| B | 0.685 | 0.695 | 17.40 | 17.65 |
| C | 0.165 | 0.180 | 4.20 | 4.57 |
| E | 0.090 | 0.110 | 2.29 | 2.79 |
| F | 0.013 | 0.019 | 0.33 | 0.48 |
| G | 0.050 BSC | | 1.27 BSC | |
| H | 0.026 | 0.032 | 0.66 | 0.81 |
| J | 0.020 | — | 0.51 | — |
| K | 0.025 | — | 0.64 | — |
| R | 0.650 | 0.656 | 16.51 | 16.66 |
| U | 0.650 | 0.656 | 16.51 | 16.66 |
| V | 0.042 | 0.048 | 1.07 | 1.21 |
| W | 0.042 | 0.048 | 1.07 | 1.21 |
| X | 0.042 | 0.056 | 1.07 | 1.42 |
| Y | — | 0.020 | — | 0.50 |
| Z | 2° | 10° | 2° | 10° |
| G1 | 0.610 | 0.630 | 15.50 | 16.00 |
| K1 | 0.040 | — | 1.02 | — |

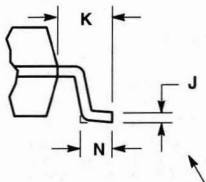
NOTES:
1. DATUMS –L–, –M–, AND –N– ARE DETERMINED WHERE TOP OF LEAD SHOULDER EXITS PLASTIC BODY AT MOLD PARTING LINE.
2. DIMENSION G1, TRUE POSITION TO BE MEASURED AT DATUM –T–, SEATING PLANE.
3. DIMENSIONS R AND U DO NOT INCLUDE MOLD FLASH. ALLOWABLE MOLD FLASH IS 0.010 (0.25) PER SIDE.
4. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
5. CONTROLLING DIMENSION: INCH.
6. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM BY UP TO 0.012 (0.300). DIMENSIONS R AND U ARE DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTERLEAD FLASH, BUT INCLUDING ANY MISMATCH BETWEEN THE TOP AND BOTTOM OF THE PLASTIC BODY.
7. DIMENSION H DOES NOT INCLUDE DAMBAR PROTRUSION OR INTRUSION. THE DAMBAR PROTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE GREATER THAN 0.037 (0.940). THE DAMBAR INTRUSION(S) SHALL NOT CAUSE THE H DIMENSION TO BE SMALLER THAN 0.025 (0.635).

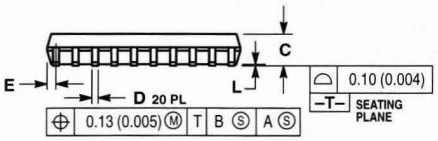
**M SUFFIX**
**CASE 803C**
**PRELIMINARY**
Plastic Package

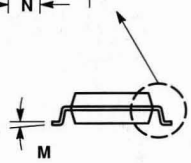








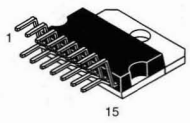

NOTES:
6 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
7 CONTROLLING DIMENSION: MILLIMETER.
8 DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
9 MAXIMUM MOLD PROTRUSION 0.15 (0.008) PER SIDE.
10 DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.006) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

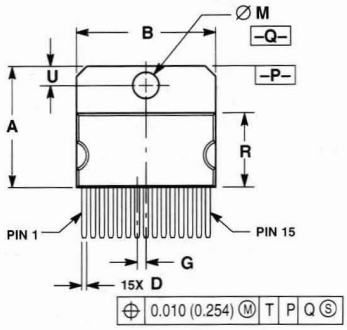
| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.35 | 12.80 | 0.486 | 0.504 |
| B | 5.10 | 5.45 | 0.201 | 0.215 |
| C | 1.95 | 2.05 | 0.077 | 0.081 |
| D | 0.35 | 0.50 | 0.014 | 0.020 |
| E | — | 0.81 | — | 0.032 |
| F | 12.40* | | 0.488* | |
| G | 1.15 | 1.39 | 0.045 | 0.055 |
| H | 0.59 | 0.81 | 0.023 | 0.032 |
| J | 0.18 | 0.27 | 0.007 | 0.011 |
| K | 1.10 | 1.50 | 0.043 | 0.059 |
| L | 0.05 | 0.20 | 0.001 | 0.008 |
| M | 0° | 10° | 0° | 10° |
| N | 0.50 | 0.85 | 0.020 | 0.033 |
| S | 7.40 | 8.20 | 0.291 | 0.323 |

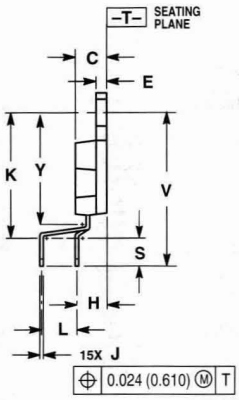
*APPROXIMATE

13

**TV SUFFIX**
**CASE 821C-04**
Plastic Package
(15-Pin ZIP)
ISSUE D



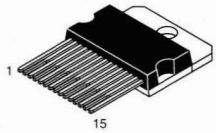



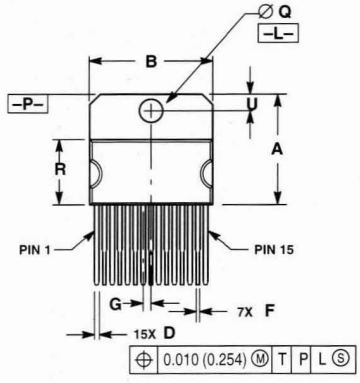



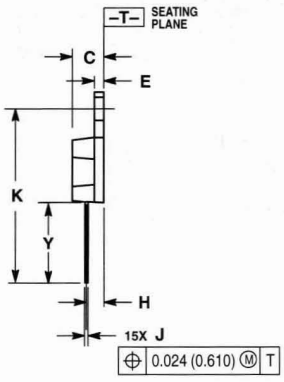

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION R DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
5. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 (0.250).
6. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE PROTRUSION SHALL BE 0.003 (0.076) TOTAL IN EXCESS OF THE D DIMENSION. AT MAXIMUM MATERIAL CONDITION.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.684 | 0.694 | 17.374 | 17.627 |
| B | 0.784 | 0.792 | 19.914 | 20.116 |
| C | 0.173 | 0.181 | 4.395 | 4.597 |
| D | 0.024 | 0.031 | 0.610 | 0.787 |
| E | 0.058 | 0.062 | 1.473 | 1.574 |
| G | 0.050 BSC | | 1.270 BSC | |
| H | 0.169 BSC | | 4.293 BSC | |
| J | 0.018 | 0.024 | 0.458 | 0.609 |
| K | 0.700 | 0.710 | 17.780 | 18.034 |
| L | 0.200 BSC | | 5.080 BSC | |
| M | 0.148 | 0.151 | 3.760 | 3.835 |
| R | 0.416 | 0.426 | 10.567 | 10.820 |
| S | 0.157 | 0.167 | 3.988 | 4.242 |
| U | 0.105 | 0.115 | 2.667 | 2.921 |
| V | 0.868 REF | | 22.047 REF | |
| Y | 0.625 | 0.639 | 15.875 | 16.231 |

**T SUFFIX**
**CASE 821D-03**
Plastic Package
ISSUE C



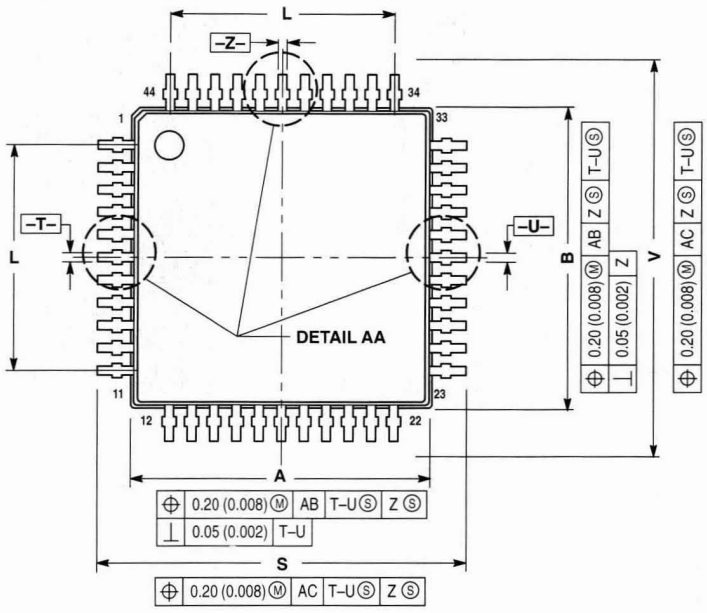



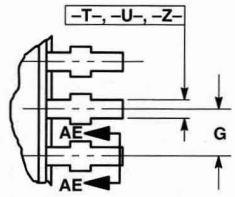

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION R DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
5. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 (0.250).
6. DELETED
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE PROTRUSION SHALL BE 0.003 (0.076) TOTAL IN EXCESS OF THE D DIMENSION. AT MAXIMUM MATERIAL CONDITION.

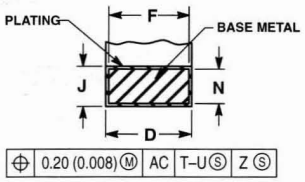
| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.681 | 0.694 | 17.298 | 17.627 |
| B | 0.784 | 0.792 | 19.914 | 20.116 |
| C | 0.173 | 0.181 | 4.395 | 4.597 |
| D | 0.024 | 0.031 | 0.610 | 0.787 |
| E | 0.058 | 0.062 | 1.473 | 1.574 |
| F | 0.016 | 0.023 | 0.407 | 0.584 |
| G | 0.050 BSC | | 1.270 BSC | |
| H | 0.110 BSC | | 2.794 BSC | |
| J | 0.018 | 0.024 | 0.458 | 0.609 |
| K | 1.078 | 1.086 | 27.382 | 27.584 |
| Q | 0.148 | 0.151 | 3.760 | 3.835 |
| R | 0.416 | 0.426 | 10.567 | 10.820 |
| U | 0.110 BSC | | 2.794 BSC | |
| Y | 0.503 REF | | 12.776 REF | |

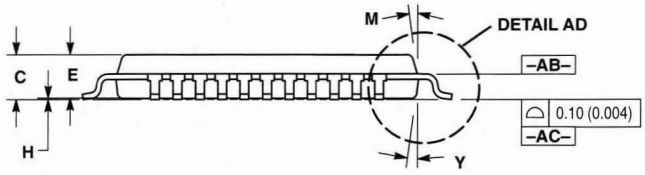
13

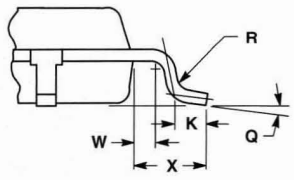
**FTB SUFFIX**
**CASE 824D–01**
Plastic Package
(TQFP–44)
ISSUE O



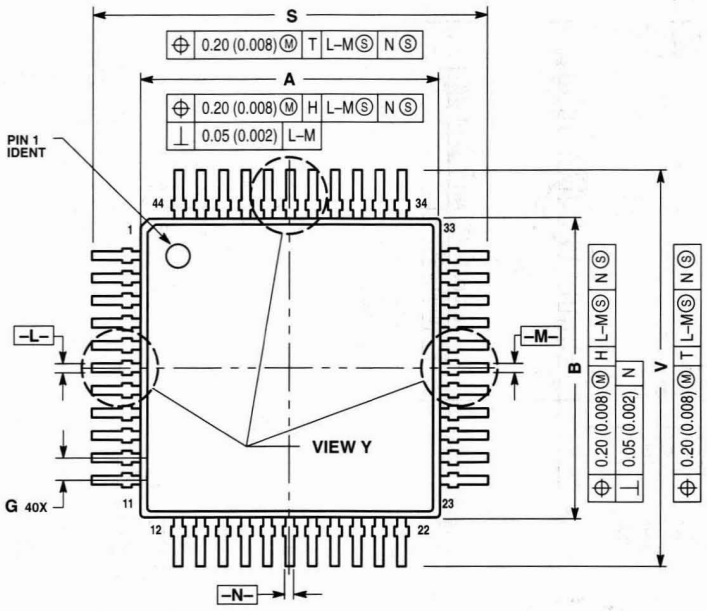

VIEW AD

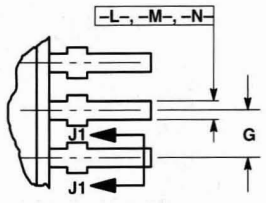
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –AB– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –T–, –U– AND –Z– TO BE DETERMINED AT DATUM PLANE –AB–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –AC–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –AB–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.530 (0.021).

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.950 | 10.050 | 0.392 | 0.396 |
| B | 9.950 | 10.050 | 0.392 | 0.396 |
| C | 1.400 | 1.600 | 0.055 | 0.063 |
| D | 0.300 | 0.450 | 0.012 | 0.018 |
| E | 1.350 | 1.450 | 0.053 | 0.057 |
| F | 0.300 | 0.400 | 0.012 | 0.016 |
| G | 0.800 BSC | | 0.031 BSC | |
| H | 0.050 | 0.150 | 0.002 | 0.006 |
| J | 0.090 | 0.200 | 0.004 | 0.008 |
| K | 0.450 | 0.550 | 0.018 | 0.022 |
| L | 8.000 BSC | | 0.315 BSC | |
| M | 12° REF | | 12° REF | |
| N | 0.090 | 0.160 | 0.004 | 0.006 |
| Q | 1° | 5° | 1° | 5° |
| R | 0.100 | 0.200 | 0.004 | 0.008 |
| S | 11.900 | 12.100 | 0.469 | 0.476 |
| V | 11.900 | 12.100 | 0.469 | 0.476 |
| W | 0.200 REF | | 0.008 REF | |
| X | 1.000 REF | | 0.039 REF | |
| Y | 12° REF | | 12° REF | |

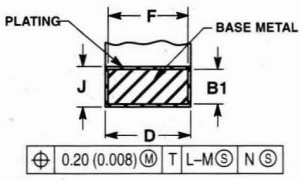
13

**FB SUFFIX**
**CASE 824E–02**
Plastic Package
(QFP)
ISSUE A

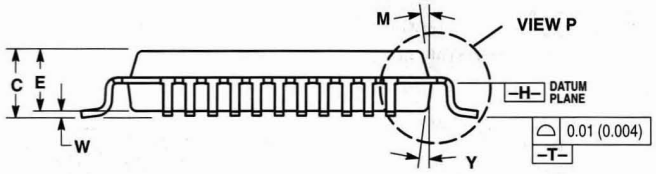


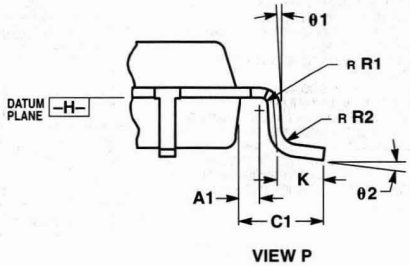




VIEW Y
3 PL




SECTION J1–J1
44 PL



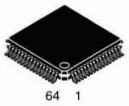

VIEW P

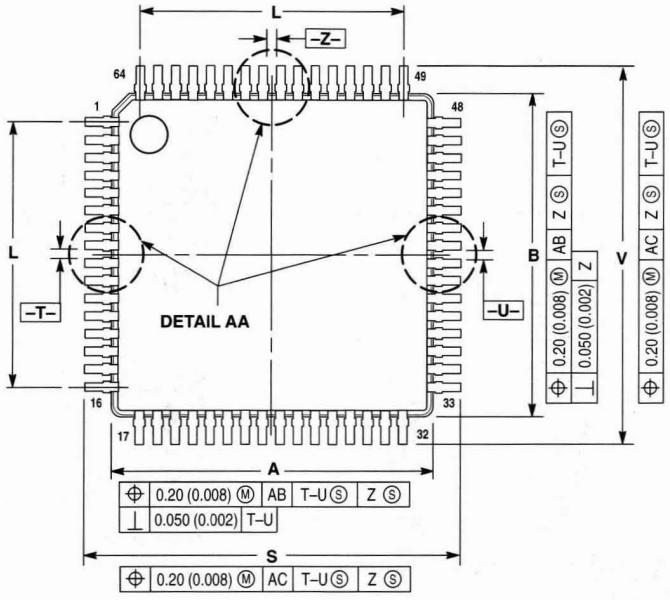
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –H– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –L–, –M– AND –N– TO BE DETERMINED AT DATUM PLANE –H–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –T–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –H–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.530 (0.021).

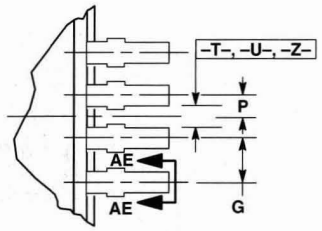
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.90 | 10.10 | 0.390 | 0.398 |
| B | 9.90 | 10.10 | 0.390 | 0.398 |
| C | 2.00 | 2.21 | 0.079 | 0.087 |
| D | 0.30 | 0.45 | 0.0118 | 0.0177 |
| E | 2.00 | 2.10 | 0.079 | 0.083 |
| F | 0.30 | 0.40 | 0.012 | 0.016 |
| G | 0.80 BSC | | 0.031 BSC | |
| J | 0.13 | 0.23 | 0.005 | 0.009 |
| K | 0.65 | 0.95 | 0.026 | 0.037 |
| M | 5° | 10° | 5° | 10° |
| S | 12.95 | 13.45 | 0.510 | 0.530 |
| V | 12.95 | 13.45 | 0.510 | 0.530 |
| W | 0.000 | 0.210 | 0.000 | 0.008 |
| Y | 5° | 10° | 5° | 10° |
| A1 | 0.450 REF | | 0.018 REF | |
| B1 | 0.130 | 0.170 | 0.005 | 0.007 |
| C1 | 1.600 REF | | 0.063 REF | |
| R1 | 0.130 | 0.300 | 0.005 | 0.012 |
| R2 | 0.130 | 0.300 | 0.005 | 0.012 |
| θ1 | 5° | 10° | 5° | 10° |
| θ2 | 0° | 7° | 0° | 7° |

13

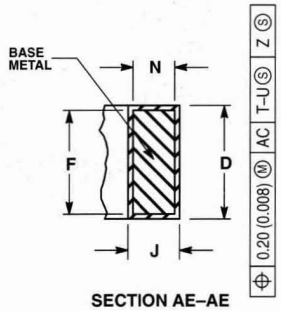
**FB SUFFIX**
**CASE 840F–01**
Plastic Package
ISSUE O



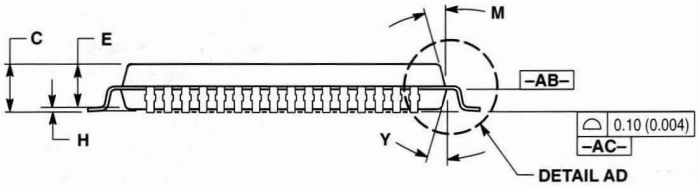



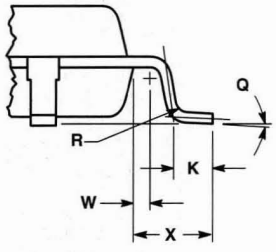

DETAIL AA




SECTION AE–AE




DETAIL AD




DETAIL AD

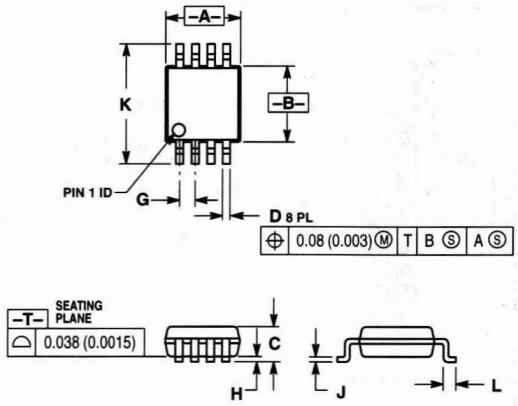
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –AB– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –T–, –U– AND –Z– TO BE DETERMINED AT DATUM PLANE –AC–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –AC–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010 ) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –AB–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.350 (0.014).

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.950 | 10.050 | 0.392 | 0.396 |
| B | 9.950 | 10.050 | 0.392 | 0.396 |
| C | 1.400 | 1.600 | 0.055 | 0.063 |
| D | 0.170 | 0.270 | 0.007 | 0.011 |
| E | 1.350 | 1.450 | 0.053 | 0.057 |
| F | 0.170 | 0.230 | 0.007 | 0.009 |
| G | 0.500 BSC | | 0.020 BSC | |
| H | 0.050 | 0.150 | 0.002 | 0.006 |
| J | 0.090 | 0.200 | 0.004 | 0.008 |
| K | 0.450 | 0.550 | 0.018 | 0.022 |
| L | 7.500 BSC | | 0.295 BSC | |
| M | 12° REF | | 12° REF | |
| N | 0.090 | 0.160 | 0.004 | 0.006 |
| P | 0.250 BSC | | 0.010 BSC | |
| Q | 1° | 5° | 1° | 5° |
| R | 0.100 | 0.200 | 0.004 | 0.008 |
| S | 11.900 | 12.100 | 0.469 | 0.476 |
| V | 11.900 | 12.100 | 0.469 | 0.476 |
| W | 0.200 REF | | 0.008 REF | |
| X | 1.000 REF | | 0.039 REF | |
| Y | 12° REF | | 12° REF | |

13

**DM SUFFIX**
**CASE 846A–02**
Plastic Package
(Micro–8)
ISSUE C



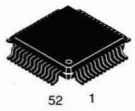



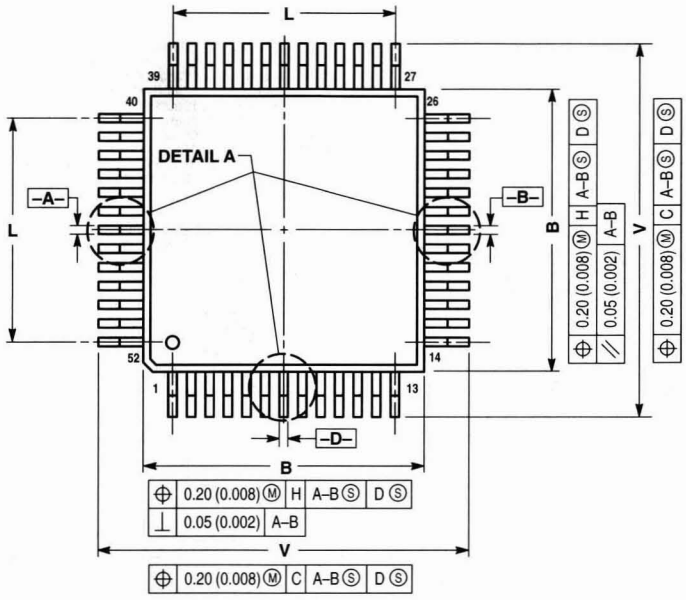

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.

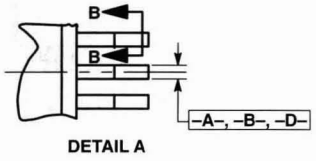
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 2.90 | 3.10 | 0.114 | 0.122 |
| B | 2.90 | 3.10 | 0.114 | 0.122 |
| C | — | 1.10 | — | 0.043 |
| D | 0.25 | 0.40 | 0.010 | 0.016 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.05 | 0.15 | 0.002 | 0.006 |
| J | 0.13 | 0.23 | 0.005 | 0.009 |
| K | 4.75 | 5.05 | 0.187 | 0.199 |
| L | 0.40 | 0.70 | 0.016 | 0.028 |

13

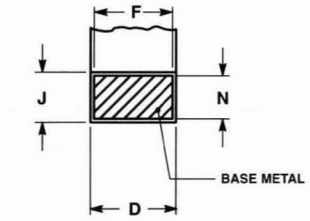
**FB SUFFIX**
**CASE 848B-04**
Plastic Package
(TQFP–52)
ISSUE C



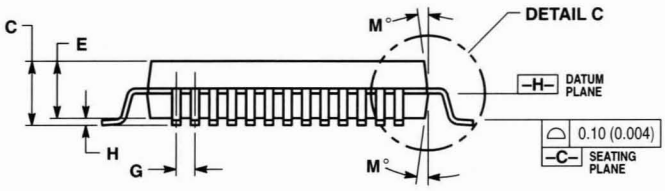



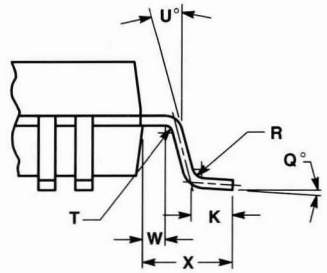




DETAIL A




SECTION B–B



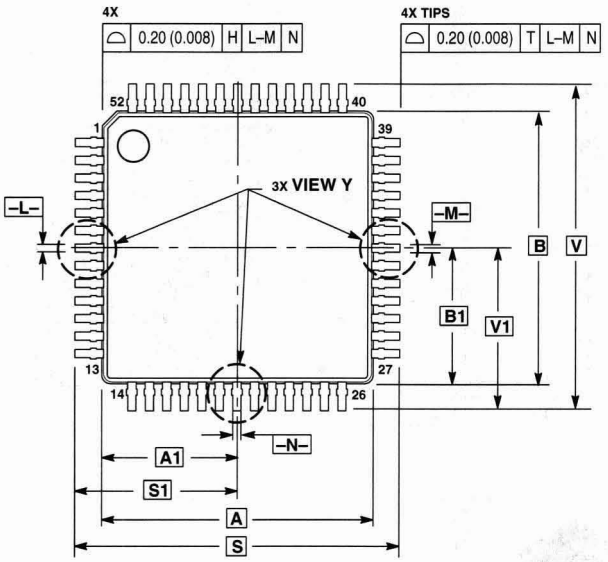

DETAIL C

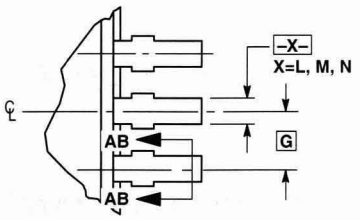
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –H– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –A–, –B– AND –D– TO BE DETERMINED AT DATUM PLANE –H–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –C–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –H–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.90 | 10.10 | 0.390 | 0.398 |
| B | 9.90 | 10.10 | 0.390 | 0.398 |
| C | 2.10 | 2.45 | 0.083 | 0.096 |
| D | 0.22 | 0.38 | 0.009 | 0.015 |
| E | 2.00 | 2.10 | 0.079 | 0.083 |
| F | 0.22 | 0.33 | 0.009 | 0.013 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | — | 0.25 | — | 0.010 |
| J | 0.13 | 0.23 | 0.005 | 0.009 |
| K | 0.65 | 0.95 | 0.026 | 0.037 |
| L | 7.80 REF | | 0.307 REF | |
| M | 5° | 10° | 5° | 10° |
| N | 0.13 | 0.17 | 0.005 | 0.007 |
| Q | 0° | 7° | 0° | 7° |
| R | 0.13 | 0.30 | 0.005 | 0.012 |
| S | 12.95 | 13.45 | 0.510 | 0.530 |
| T | 0.13 | — | 0.005 | — |
| U | 0° | — | 0° | — |
| V | 12.95 | 13.45 | 0.510 | 0.530 |
| W | 0.35 | 0.45 | 0.014 | 0.018 |
| X | 1.6 REF | | 0.063 REF | |

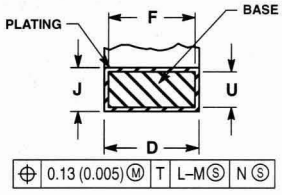
13

**FB SUFFIX**
**CASE 848D–03**
Plastic Package
ISSUE C

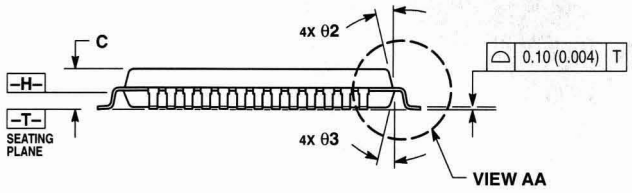


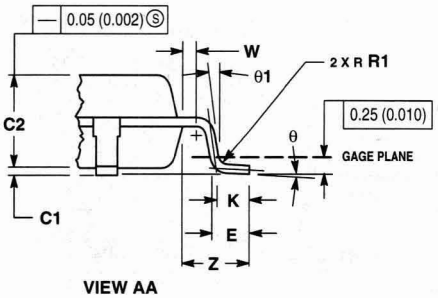

VIEW Y




SECTION AB–AB
ROTATED 90° CLOCKWISE




VIEW AA



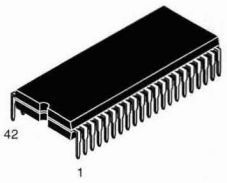

VIEW AA

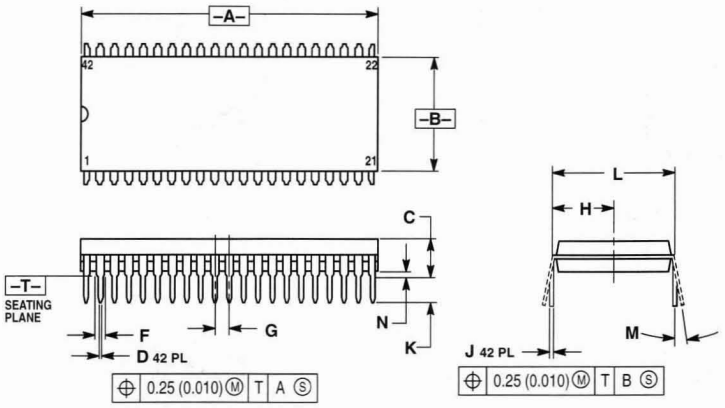
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –H– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –L–, –M– AND –N– TO BE DETERMINED AT DATUM PLANE –H–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –T–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE -H-.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.46 (0.018). MINIMUM SPACE BETWEEN PROTRUSION AND ADJACENT LEAD OR PROTRUSION 0.07 (0.003).

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 10.00 BSC | | 0.394 BSC | |
| A1 | 5.00 BSC | | 0.197 BSC | |
| B | 10.00 BSC | | 0.394 BSC | |
| B1 | 5.00 BSC | | 0.197 BSC | |
| C | — | 1.70 | — | 0.067 |
| C1 | 0.05 | 0.20 | 0.002 | 0.008 |
| C2 | 1.30 | 1.50 | 0.051 | 0.059 |
| D | 0.20 | 0.40 | 0.008 | 0.016 |
| E | 0.45 | 0.75 | 0.018 | 0.030 |
| F | 0.22 | 0.35 | 0.009 | 0.014 |
| G | 0.65 BSC | | 0.026 BSC | |
| J | 0.07 | 0.20 | 0.003 | 0.008 |
| K | 0.50 REF | | 0.020 REF | |
| R1 | 0.08 | 0.20 | 0.003 | 0.008 |
| S | 12.00 BSC | | 0.472 BSC | |
| S1 | 6.00 BSC | | 0.236 BSC | |
| U | 0.09 | 0.16 | 0.004 | 0.006 |
| V | 12.00 BSC | | 0.472 BSC | |
| V1 | 6.00 BSC | | 0.236 BSC | |
| W | 0.20 REF | | 0.008 REF | |
| Z | 1.00 REF | | 0.039 REF | |
| θ | 0° | 7° | 0° | 7° |
| θ1 | 0° | — | 0° | — |
| θ2 | 12° REF | | 12° REF | |
| θ3 | 5° | 13° | 5° | 13° |

13

**B SUFFIX**
**CASE 858–01**
Plastic Package
ISSUE O

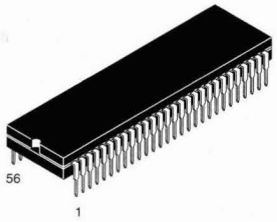


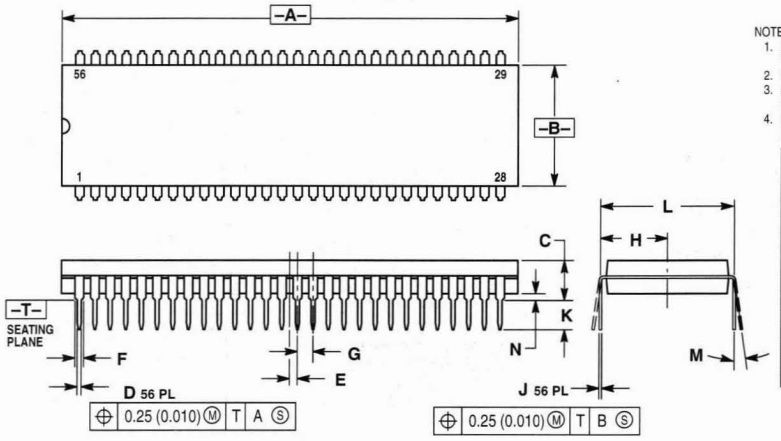




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
4. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH. MAXIMUM MOLD FLASH 0.25 (0.010).

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 1.435 | 1.465 | 36.45 | 37.21 |
| B | 0.540 | 0.560 | 13.72 | 14.22 |
| C | 0.155 | 0.200 | 3.94 | 5.08 |
| D | 0.014 | 0.022 | 0.36 | 0.56 |
| F | 0.032 | 0.046 | 0.81 | 1.17 |
| G | 0.070 BSC | | 1.778 BSC | |
| H | 0.300 BSC | | 7.62 BSC | |
| J | 0.008 | 0.015 | 0.20 | 0.38 |
| K | 0.115 | 0.135 | 2.92 | 3.43 |
| L | 0.600 BSC | | 15.24 BSC | |
| M | 0 ° | 15 ° | 0 ° | 15 ° |
| N | 0.020 | 0.040 | 0.51 | 1.02 |

**B SUFFIX**
**CASE 859–01**
Plastic Package
(SDIP)
ISSUE O



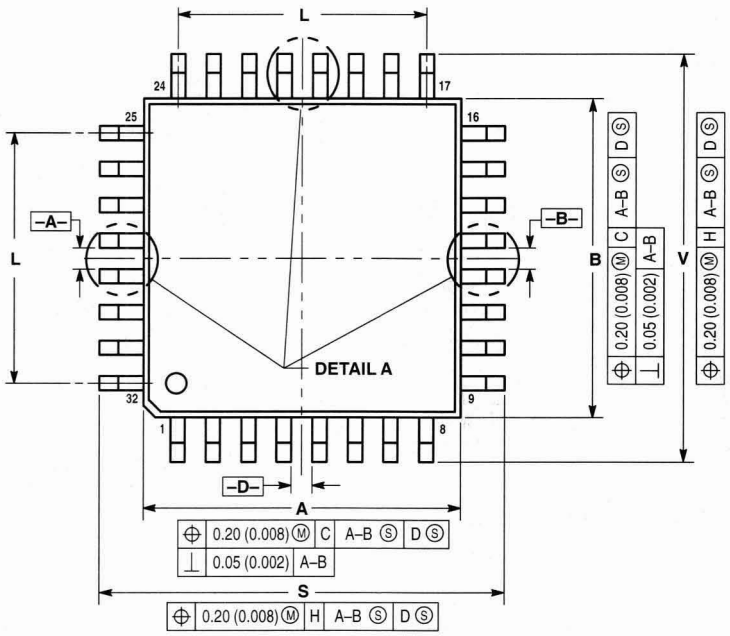



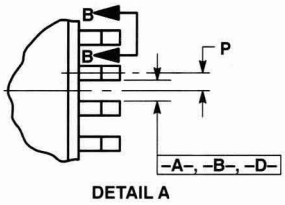

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
4. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH. MAXIMUM MOLD FLASH 0.25 (0.010)

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 2.035 | 2.065 | 51.69 | 52.45 |
| B | 0.540 | 0.560 | 13.72 | 14.22 |
| C | 0.155 | 0.200 | 3.94 | 5.08 |
| D | 0.014 | 0.022 | 0.36 | 0.56 |
| E | 0.035 BSC | | 0.89 BSC | |
| F | 0.032 | 0.046 | 0.81 | 1.17 |
| G | 0.070 BSC | | 1.778 BSC | |
| H | 0.300 BSC | | 7.62 BSC | |
| J | 0.008 | 0.015 | 0.20 | 0.38 |
| K | 0.115 | 0.135 | 2.92 | 3.43 |
| L | 0.600 BSC | | 15.24 BSC | |
| M | 0 ° | 15 ° | 0 ° | 15 ° |
| N | 0.020 | 0.040 | 0.51 | 1.02 |

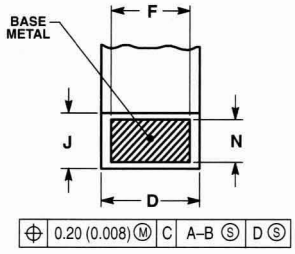
13

**FB, FTB SUFFIX**
**CASE 873-01**
Plastic Package
(TQFP–32)
ISSUE A

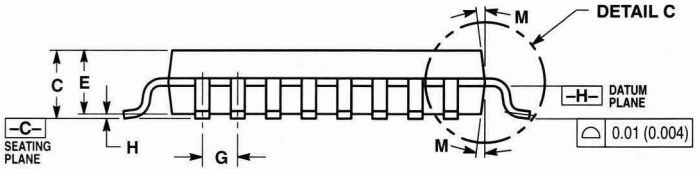


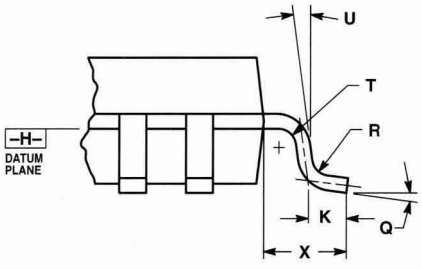




DETAIL A




SECTION B–B
VIEW ROTATED 90 ° CLOCKWISE



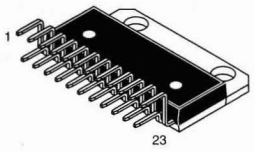

DETAIL C

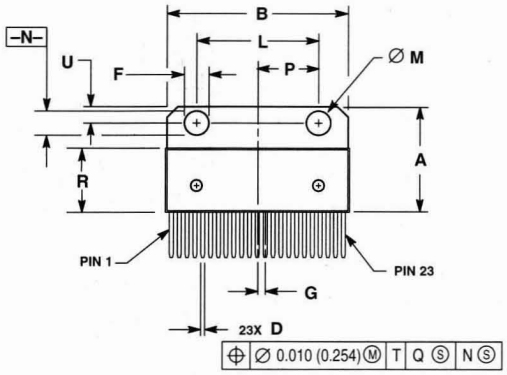
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –H– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –A–, –B– AND –D– TO BE DETERMINED AT DATUM PLANE –H–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –C–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –H–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT.

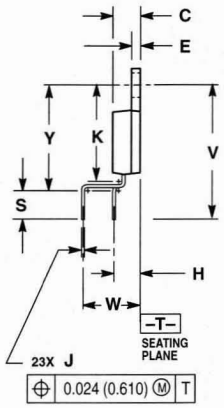
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 6.95 | 7.10 | 0.274 | 0.280 |
| B | 6.95 | 7.10 | 0.274 | 0.280 |
| C | 1.40 | 1.60 | 0.055 | 0.063 |
| D | 0.273 | 0.373 | 0.010 | 0.015 |
| E | 1.30 | 1.50 | 0.051 | 0.059 |
| F | 0.273 | — | 0.010 | — |
| G | 0.80 BSC | | 0.031 BSC | |
| H | — | 0.20 | — | 0.008 |
| J | 0.119 | 0.197 | 0.005 | 0.008 |
| K | 0.33 | 0.57 | 0.013 | 0.022 |
| L | 5.6 REF | | 0.220 REF | |
| M | 6° | 8° | 6° | 8° |
| N | 0.119 | 0.135 | 0.005 | 0.005 |
| P | 0.40 BSC | | 0.016 BSC | |
| Q | 5° | 10° | 5° | 10° |
| R | 0.15 | 0.25 | 0.006 | 0.010 |
| S | 8.85 | 9.15 | 0.348 | 0.360 |
| T | 0.15 | 0.25 | 0.006 | 0.010 |
| U | 5° | 11° | 5° | 11° |
| V | 8.85 | 9.15 | 0.348 | 0.360 |
| X | 1.00 REF | | 0.039 REF | |

13

**T SUFFIX**
**CASE 894-03**
Plastic Package
(23-Pin SZIP)
ISSUE B



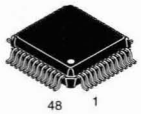



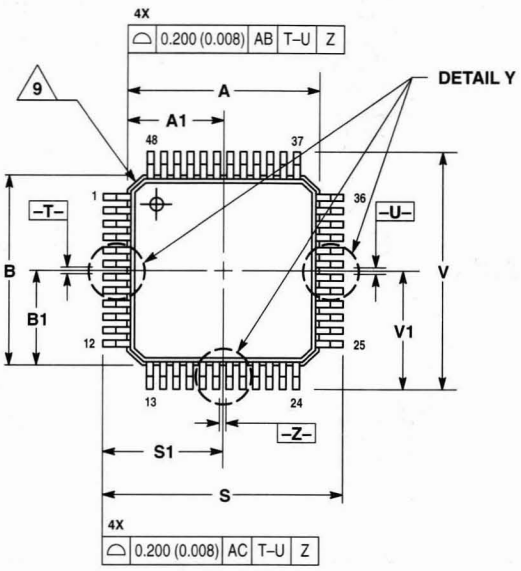

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION R DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
5. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 (0.250).
6. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE PROTRUSION SHALL BE 0.003 (0.076) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

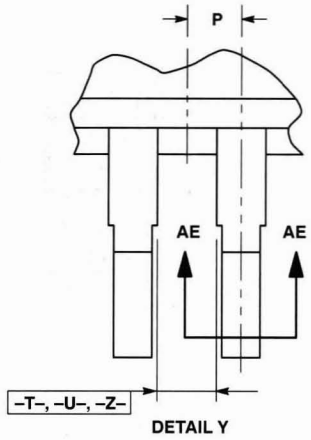
| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.684 | 0.694 | 17.374 | 17.627 |
| B | 1.183 | 1.193 | 30.048 | 30.302 |
| C | 0.175 | 0.179 | 4.445 | 4.547 |
| D | 0.026 | 0.031 | 0.660 | 0.787 |
| E | 0.058 | 0.062 | 1.473 | 1.574 |
| F | 0.165 | 0.175 | 4.191 | 4.445 |
| G | 0.050 BSC | | 1.270 BSC | |
| H | 0.169 BSC | | 4.293 BSC | |
| J | 0.014 | 0.020 | 0.356 | 0.508 |
| K | 0.625 | 0.639 | 15.875 | 16.231 |
| L | 0.770 | 0.790 | 19.558 | 20.066 |
| M | 0.148 | 0.152 | 3.760 | 3.861 |
| N | 0.148 | 0.152 | 3.760 | 3.861 |
| P | 0.390 BSC | | 9.906 BSC | |
| R | 0.416 | 0.424 | 10.566 | 10.770 |
| S | 0.157 | 0.167 | 3.988 | 4.242 |
| U | 0.105 | 0.115 | 2.667 | 2.921 |
| V | 0.868 REF | | 22.047 REF | |
| W | 0.200 BSC | | 5.080 BSC | |
| Y | 0.700 | 0.710 | 17.780 | 18.034 |

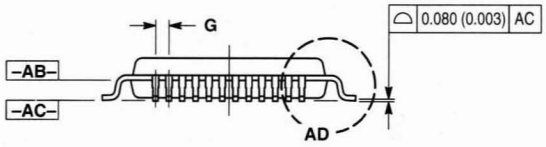
13

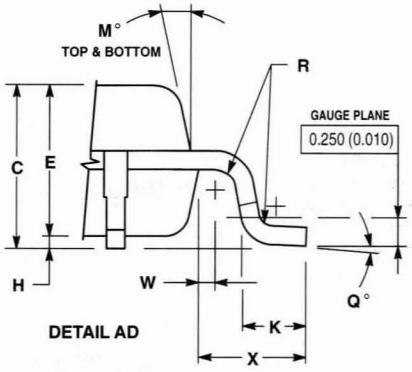
**FTA SUFFIX**
**CASE 932–02**
Plastic Package
(TQFP–48)
ISSUE D

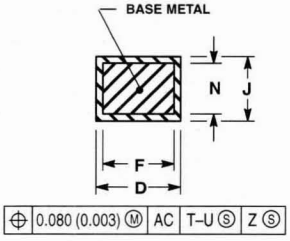


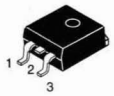



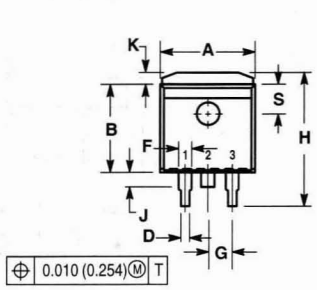

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –AB– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –T–, –U–, AND –Z– TO BE DETERMINED AT DATUM PLANE –AB–.
5. DIMENSIONS S AND V TO BE DETERMINED AT SEATING PLANE –AC–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.250 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –AB–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.350 (0.014).
8. MINIMUM SOLDER PLATE THICKNESS SHALL BE 0.0076 (0.0003).
9. EXACT SHAPE OF EACH CORNER IS OPTIONAL.

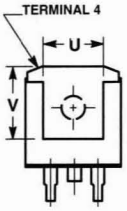
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 7.000 BSC | | 0.276 BSC | |
| A1 | 3.500 BSC | | 0.138 BSC | |
| B | 7.000 BSC | | 0.276 BSC | |
| B1 | 3.500 BSC | | 0.138 BSC | |
| C | 1.400 | 1.600 | 0.055 | 0.063 |
| D | 0.170 | 0.270 | 0.007 | 0.011 |
| E | 1.350 | 1.450 | 0.053 | 0.057 |
| F | 0.170 | 0.230 | 0.007 | 0.009 |
| G | 0.500 BASIC | | 0.020 BASIC | |
| H | 0.050 | 0.150 | 0.002 | 0.006 |
| J | 0.090 | 0.200 | 0.004 | 0.008 |
| K | 0.500 | 0.700 | 0.020 | 0.028 |
| M | 12 °REF | | 12 °REF | |
| N | 0.090 | 0.160 | 0.004 | 0.006 |
| P | 0.250 BASIC | | 0.010 BASIC | |
| Q | 1° | 5° | 1° | 5° |
| R | 0.150 | 0.250 | 0.006 | 0.010 |
| S | 9.000 BSC | | 0.354 BSC | |
| S1 | 4.500 BSC | | 0.177 BSC | |
| V | 9.000 BSC | | 0.354 BSC | |
| V1 | 4.500 BSC | | 0.177 BSC | |
| W | 0.200 REF | | 0.008 REF | |
| X | 1.000 REF | | 0.039 REF | |

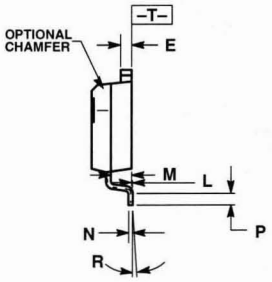
13

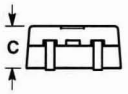
**D2T SUFFIX**
**CASE 936–03**
Plastic Package
ISSUE B



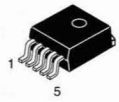



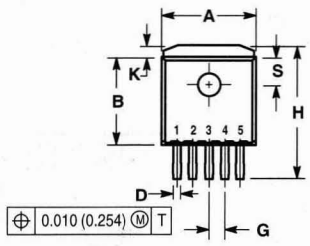



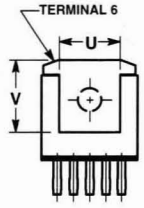

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. TAB CONTOUR OPTIONAL WITHIN DIMENSIONS A AND K.
4. DIMENSIONS U AND V ESTABLISH A MINIMUM MOUNTING SURFACE FOR TERMINAL 4.
5. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH OR GATE PROTRUSIONS. MOLD FLASH AND GATE PROTRUSIONS NOT TO EXCEED 0.025 (0.635) MAXIMUM.

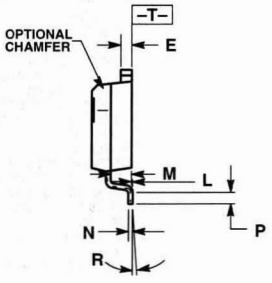
| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.386 | 0.403 | 9.804 | 10.236 |
| B | 0.356 | 0.368 | 9.042 | 9.347 |
| C | 0.170 | 0.180 | 4.318 | 4.572 |
| D | 0.026 | 0.036 | 0.660 | 0.914 |
| E | 0.045 | 0.055 | 1.143 | 1.397 |
| F | 0.051 REF | | 1.295 REF | |
| G | 0.100 BSC | | 2.540 BSC | |
| H | 0.539 | 0.579 | 13.691 | 14.707 |
| J | 0.125 MAX | | 3.175 MAX | |
| K | 0.050 REF | | 1.270 REF | |
| L | 0.000 | 0.010 | 0.000 | 0.254 |
| M | 0.088 | 0.102 | 2.235 | 2.591 |
| N | 0.018 | 0.026 | 0.457 | 0.660 |
| P | 0.058 | 0.078 | 1.473 | 1.981 |
| R | 5° REF | | 5° REF | |
| S | 0.116 REF | | 2.946 REF | |
| U | 0.200 MIN | | 5.080 MIN | |
| V | 0.250 MIN | | 6.350 MIN | |

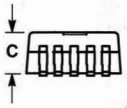
**D2T SUFFIX**
**CASE 936A–02**
Plastic Package
($D^2PAK$)
ISSUE A



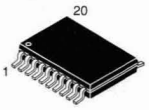



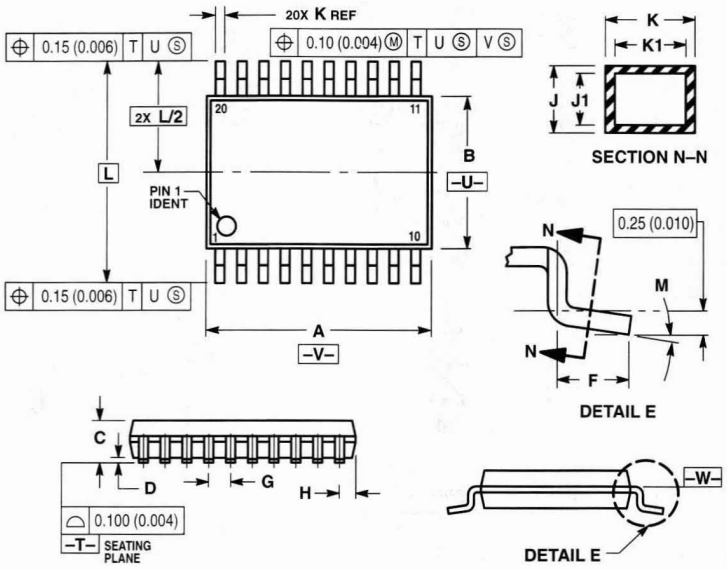

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. TAB CONTOUR OPTIONAL WITHIN DIMENSIONS A AND K.
4. DIMENSIONS U AND V ESTABLISH A MINIMUM MOUNTING SURFACE FOR TERMINAL 6.
5. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH OR GATE PROTRUSIONS. MOLD FLASH AND GATE PROTRUSIONS NOT TO EXCEED 0.025 (0.635) MAXIMUM.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.386 | 0.403 | 9.804 | 10.236 |
| B | 0.356 | 0.368 | 9.042 | 9.347 |
| C | 0.170 | 0.180 | 4.318 | 4.572 |
| D | 0.026 | 0.036 | 0.660 | 0.914 |
| E | 0.045 | 0.055 | 1.143 | 1.397 |
| G | 0.067 BSC | | 1.702 BSC | |
| H | 0.539 | 0.579 | 13.691 | 14.707 |
| K | 0.050 REF | | 1.270 REF | |
| L | 0.000 | 0.010 | 0.000 | 0.254 |
| M | 0.088 | 0.102 | 2.235 | 2.591 |
| N | 0.018 | 0.026 | 0.457 | 0.660 |
| P | 0.058 | 0.078 | 1.473 | 1.981 |
| R | 5° REF | | 5° REF | |
| S | 0.116 REF | | 2.946 REF | |
| U | 0.200 MIN | | 5.080 MIN | |
| V | 0.250 MIN | | 6.350 MIN | |

13

**DT, DTB SUFFIX**
**CASE 948E–02**
Plastic Package
(TSSOP–20)
ISSUE A

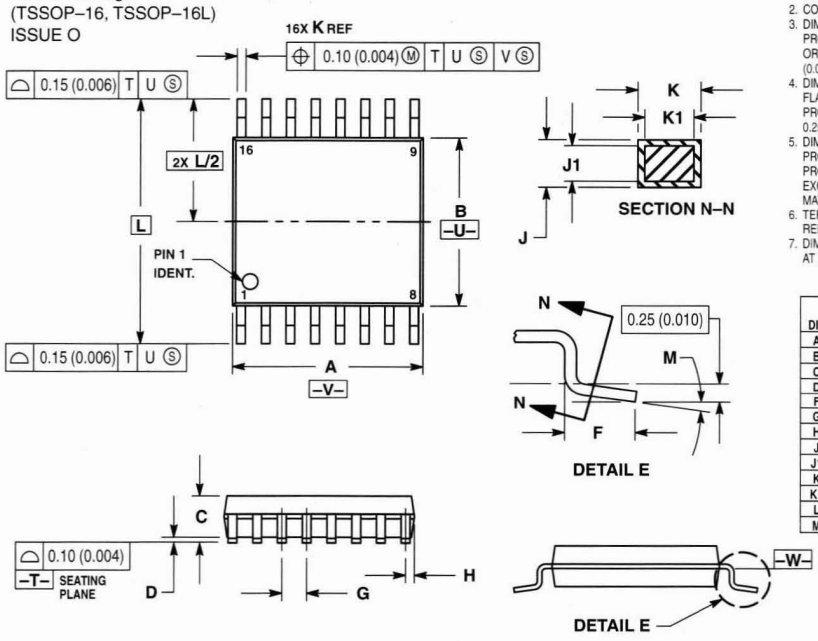



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5. DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7. DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 6.40 | 6.60 | 0.252 | 0.260 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.27 | 0.37 | 0.011 | 0.015 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0° | 8° | 0° | 8° |

**DTB SUFFIX**
**CASE 948F–01**
Plastic Package
(TSSOP–16, TSSOP–16L)
ISSUE O

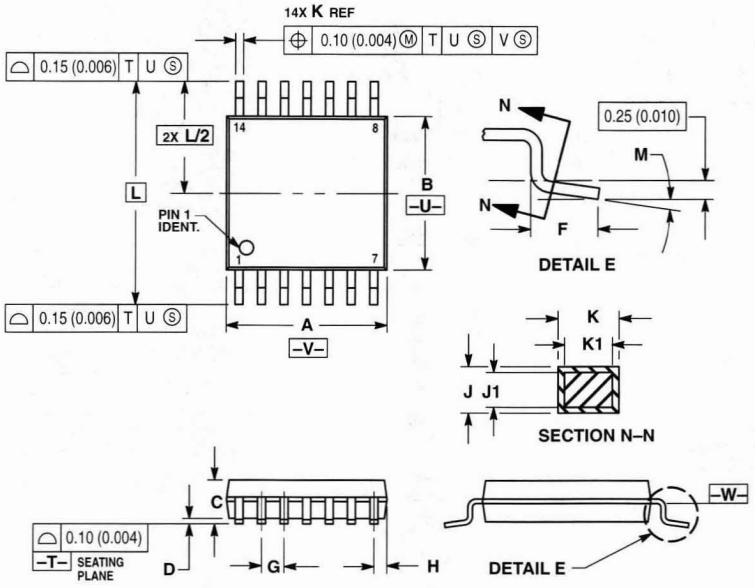



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5. DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7. DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 4.90 | 5.10 | 0.193 | 0.200 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.18 | 0.28 | 0.007 | 0.011 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0° | 8° | 0° | 8° |

13

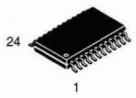
**DTB SUFFIX**
**CASE 948G–01**
Plastic Package
(TSSOP–14)
ISSUE O

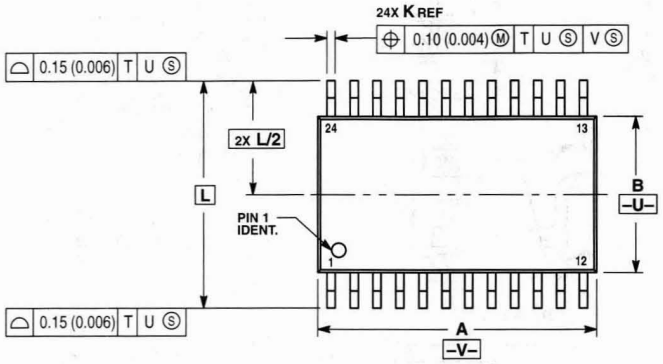



NOTES:
1 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION: MILLIMETER.
3 DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4 DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5 DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6 TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7 DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.

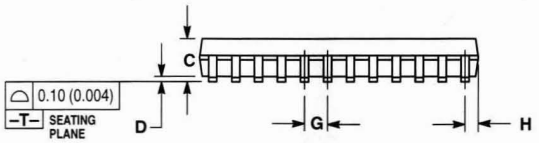
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 4.90 | 5.10 | 0.193 | 0.200 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.50 | 0.60 | 0.020 | 0.024 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0° | 8° | 0° | 8° |

**DTB SUFFIX**
**CASE 948H–01**
Plastic Package
ISSUE O

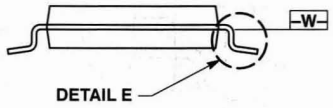


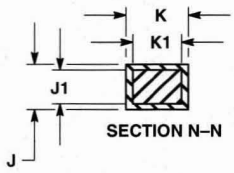



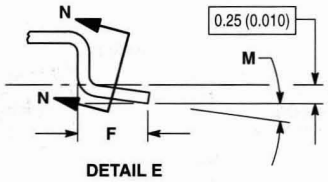

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5. DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7. DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.




| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 7.70 | 7.90 | 0.303 | 0.311 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.27 | 0.37 | 0.011 | 0.015 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0° | 8° | 0° | 8° |

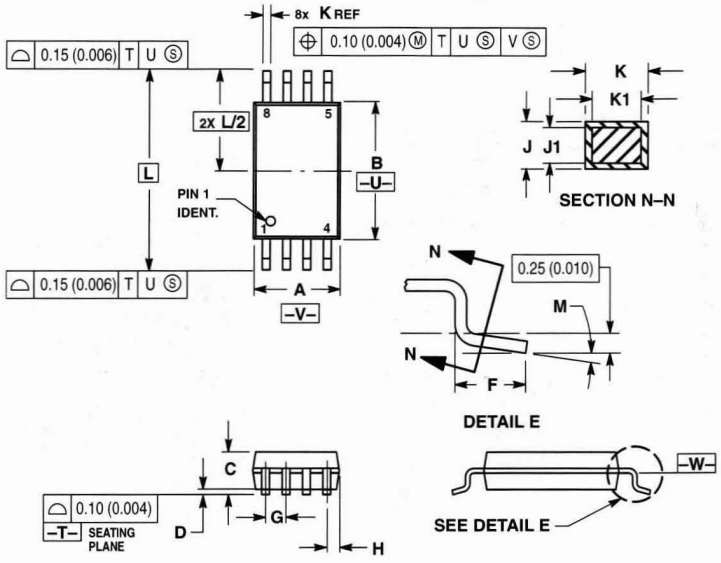



13

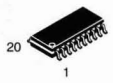
**DTB SUFFIX**
**CASE 948J–01**
Plastic Package
(TSSOP–8)
ISSUE O

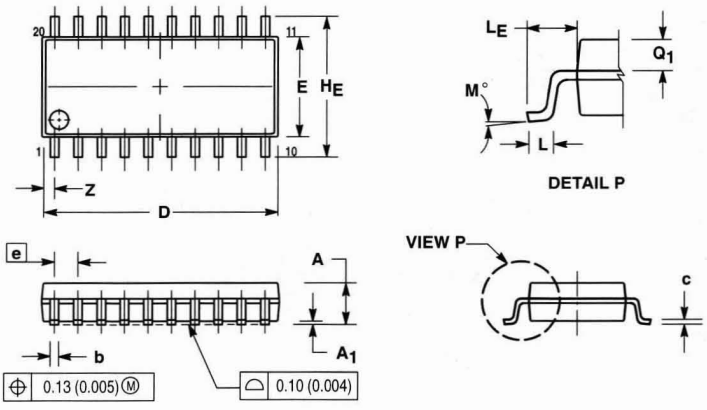



NOTES:
1 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION: MILLIMETER.
3 DIMENSION A DOES NOT INCLUDE MOLD FLASH. PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4 DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5 DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6 TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7 DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 2.90 | 3.10 | 0.114 | 0.122 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.50 | 0.60 | 0.020 | 0.024 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0° | 8° | 0° | 8° |

**M SUFFIX**
**CASE 967–01**
Plastic Package
(EIAJ–20)
ISSUE O





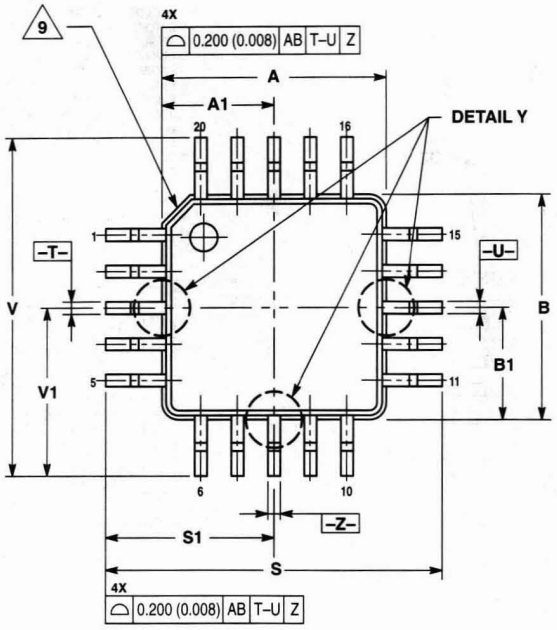

NOTES:
1 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION: MILLIMETER.
3 DIMENSIONS D AND E DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS AND ARE MEASURED AT THE PARTING LINE. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4 TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
5 THE LEAD WIDTH DIMENSION (b) DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE LEAD WIDTH DIMENSION AT MAXIMUM MATERIAL CONDITION. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT. MINIMUM SPACE BETWEEN PROTRUSIONS AND ADJACENT LEAD TO BE 0.46 ( 0.018).

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | — | 2.05 | — | 0.081 |
| $A_1$ | 0.05 | 0.20 | 0.002 | 0.008 |
| b | 0.35 | 0.50 | 0.014 | 0.020 |
| c | 0.18 | 0.27 | 0.007 | 0.011 |
| D | 12.35 | 12.80 | 0.486 | 0.504 |
| E | 5.10 | 5.45 | 0.201 | 0.215 |
| e | 1.27 BSC | | 0.050 BSC | |
| $H_E$ | 7.40 | 8.20 | 0.291 | 0.323 |
| L | 0.50 | 0.85 | 0.020 | 0.033 |
| $L_E$ | 1.10 | 1.50 | 0.043 | 0.059 |
| M | 0° | 10° | 0° | 10° |
| $Q_1$ | 0.70 | 0.90 | 0.028 | 0.035 |
| Z | — | 0.81 | — | 0.032 |

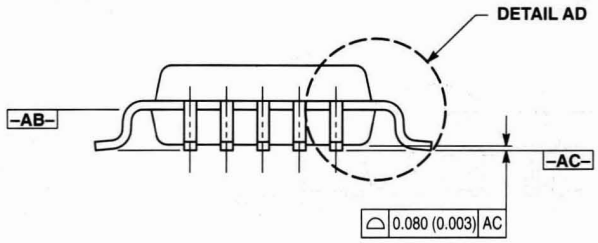
13

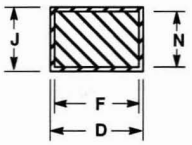
**FTB SUFFIX**
**CASE 976–01**
Plastic Package
(TQFP–20)
ISSUE O

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –AB– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –T–, –U–, AND –Z– TO BE DETERMINED AT DATUM PLANE –AB–.
5. DIMENSIONS S AND V TO BE DETERMINED AT DATUM PLANE –AC–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.250 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –AB–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.350 (0.014).
8. MINIMUM SOLDER PLATE THICKNESS SHALL BE 0.0076 (0.0003).
9. EXACT SHAPE OF EACH CORNER IS OPTIONAL.



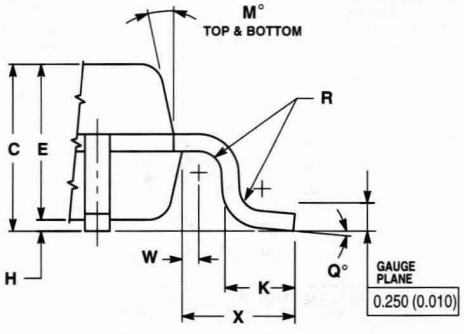

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 4.000 BSC | | 0.157 BSC | |
| A1 | 2.000 BSC | | 0.079 BSC | |
| B | 4.000 BSC | | 0.157 BSC | |
| B1 | 2.000 BSC | | 0.079 BSC | |
| C | 1.400 | 1.600 | 0.055 | 0.063 |
| D | 0.170 | 0.270 | 0.007 | 0.011 |
| E | 1.350 | 1.450 | 0.053 | 0.057 |
| F | 0.170 | 0.230 | 0.007 | 0.009 |
| G | 0.650 BSC | | 0.026 BSC | |
| H | 0.050 | 0.150 | 0.002 | 0.006 |
| J | 0.090 | 0.200 | 0.004 | 0.008 |
| K | 0.500 | 0.700 | 0.020 | 0.028 |
| M | 12° REF | | 12° REF | |
| N | 0.090 | 0.160 | 0.004 | 0.006 |
| P | 0.250 BSC | | 0.010 BSC | |
| Q | 1° | 5° | 1° | 5° |
| R | 0.150 | 0.250 | 0.006 | 0.010 |
| S | 6.000 BSC | | 0.236 BSC | |
| S1 | 3.000 BSC | | 0.118 BSC | |
| V | 6.000 BSC | | 0.236 BSC | |
| V1 | 3.000 BSC | | 0.118 BSC | |
| W | 0.200 REF | | 0.008 REF | |
| X | 1.000 REF | | 0.039 REF | |



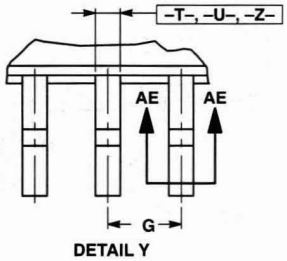




0.080 (0.003) Ⓢ AC T–U Ⓢ Z Ⓢ

**SECTION AE–AE**




**DETAIL AD**

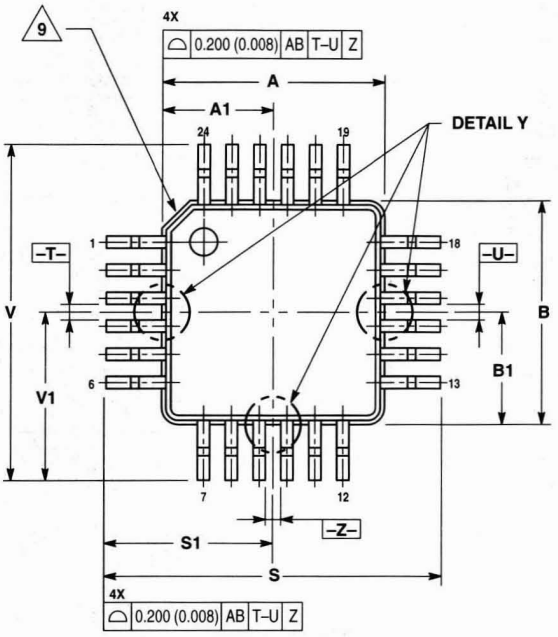



**DETAIL Y**

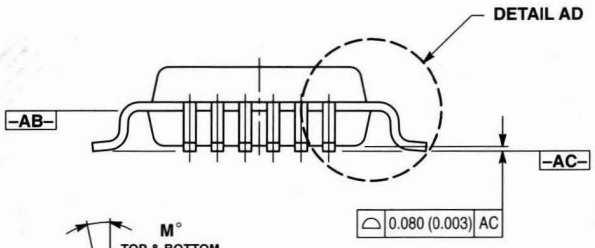
13

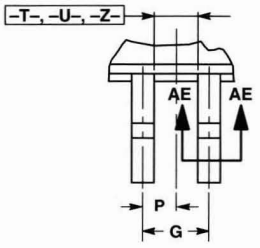
**FTA SUFFIX**
**CASE 977–01**
Plastic Package
ISSUE O

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DATUM PLANE –AB– IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
4. DATUMS –T–, –U–, AND –Z– TO BE DETERMINED AT DATUM PLANE –AB–.
5. DIMENSIONS S AND V TO BE DETERMINED AT DATUM PLANE –AC–.
6. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.250 (0.010) PER SIDE. DIMENSIONS A AND B DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE –AB–.
7. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE D DIMENSION TO EXCEED 0.350 (0.014).
8. MINIMUM SOLDER PLATE THICKNESS SHALL BE 0.0076 (0.0003).
9. EXACT SHAPE OF EACH CORNER IS OPTIONAL.

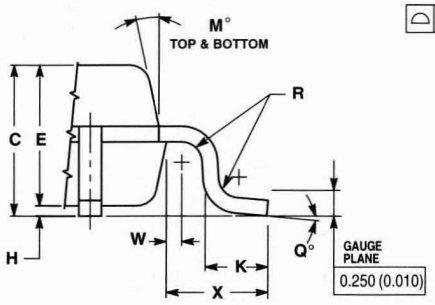



| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 4.000 BSC | | 0.157 BSC | |
| A1 | 2.000 BSC | | 0.079 BSC | |
| B | 4.000 BSC | | 0.157 BSC | |
| B1 | 2.000 BSC | | 0.079 BSC | |
| C | 1.400 | 1.600 | 0.055 | 0.063 |
| D | 0.170 | 0.270 | 0.007 | 0.011 |
| E | 1.350 | 1.450 | 0.053 | 0.057 |
| F | 0.170 | 0.230 | 0.007 | 0.009 |
| G | 0.500 BSC | | 0.020 BSC | |
| H | 0.050 | 0.150 | 0.002 | 0.006 |
| J | 0.090 | 0.200 | 0.004 | 0.008 |
| K | 0.500 | 0.700 | 0.020 | 0.028 |
| M | 12° REF | | 12° REF | |
| N | 0.090 | 0.160 | 0.004 | 0.006 |
| P | 0.250 BSC | | 0.010 BSC | |
| Q | 1° | 5° | 1° | 5° |
| R | 0.150 | 0.250 | 0.006 | 0.010 |
| S | 6.000 BSC | | 0.236 BSC | |
| S1 | 3.000 BSC | | 0.118 BSC | |
| V | 6.000 BSC | | 0.236 BSC | |
| V1 | 3.000 BSC | | 0.118 BSC | |
| W | 0.200 REF | | 0.008 REF | |
| X | 1.000 REF | | 0.039 REF | |

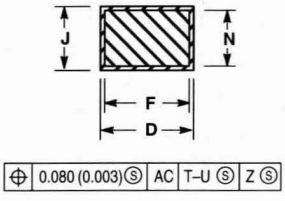



DETAIL Y



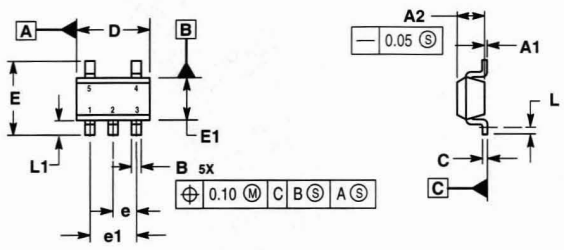

DETAIL AD




SECTION AE–AE

13

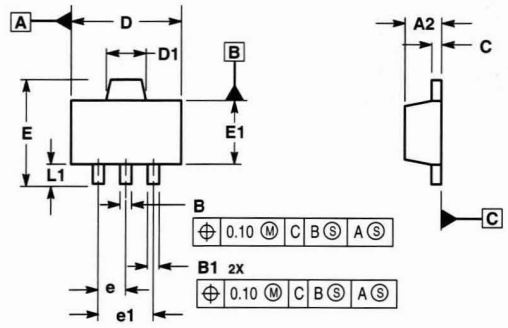
**N SUFFIX**
**CASE 1212–01**
Plastic Package
(SOT–23)
ISSUE O




NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. DATUM C IS A SEATING PLANE.

| | MILLIMETERS | |
|---|---|---|
| DIM | MIN | MAX |
| A1 | 0.00 | 0.10 |
| A2 | 1.00 | 1.30 |
| B | 0.30 | 0.50 |
| C | 0.10 | 0.25 |
| D | 2.80 | 3.00 |
| E | 2.50 | 3.10 |
| E1 | 1.50 | 1.80 |
| e | 0.95 BSC | |
| e1 | 1.90 BSC | |
| L | 0.20 | — |
| L1 | 0.45 | 0.75 |

**H SUFFIX**
**CASE 1213–01**
Plastic Package
(SOT–89)
ISSUE O




NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCING PER ASME Y14.5M, 1994.
3. DATUM C IS A SEATING PLANE.

| | MILLIMETERS | |
|---|---|---|
| DIM | MIN | MAX |
| A2 | 1.40 | 1.60 |
| B | 0.37 | 0.57 |
| B1 | 0.32 | 0.52 |
| C | 0.30 | 0.50 |
| D | 4.40 | 4.60 |
| D1 | 1.50 | 1.70 |
| E | — | 4.25 |
| E1 | 2.40 | 2.60 |
| e | 1.50 BSC | |
| e1 | 3.00 BSC | |
| L1 | 0.80 | — |

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# Quality and Reliability Assurance

## In Brief . . .

*The word quality has been used to describe many things, such as fitness for use, customer satisfaction, customer enthusiasm, what the customer says quality is, etc. These descriptions convey important truths, however, quality should be described in a way that precipitates immediate action. With that in mind, quality can be described as reduction of variability around a target, so that conformance to customer requirements and possibly expectations can be achieved in a cost effective way. This definition provides direction and potential for immediate action for a person desiring to improve quality.*

*The definition of quality as described above can be applied to a task, process or a whole company. If we are to reap the benefits of quality and obtain a competitive advantage, quality must be applied to the whole company.*

*Implementation of quality ideas company wide requires a quality plan showing: a philosophy (belief) of operation, measurable goals, training of individuals and methods of communicating this philosophy of operation to the whole organization.*

*Motorola, for example, believes that quality and reliability are the responsibility of every person. Participative Management is the process by which problem solving and quality improvement are facilitated at all levels of the organization through crossfunctional teams. Continuous improvement for the individual is facilitated by a broad educational program covering onsite, university and college courses. Motorola University provides leadership and administers this educational effort on a company wide basis.*

*Another key belief is that quality excellence is accomplished by people doing things right the first time and committed to never ending improvement. The Six Sigma (6σ) challenge is designed to convey and facilitate the idea of continuous improvement at all levels.*

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# Quality Concepts

**Quality improvement** for a task or a process can be quickly described in terms of the target, current status with respect to target (variability), reduction of variability (commitment to never ending improvement), customer requirements (who receives output, what are a person's requirements/ expectations) and economics (cost of nonconformance, loss function, etc.).

Application of quality to the whole company has come to be known by such names as **"Total Quality Control" (TQC); "Company Wide Quality Control" (CWQC); "Total Quality Excellence" or "Total Quality Engineering" (TQE); "Total Quality Involvement" (TQI).** These names attempt to convey the idea that quality is a process (a way of acting continuously) rather than a program (implying a beginning and an end). Nevertheless for this process to be successful it must be able to show measurable results.

"**Six Sigma** is the required capability level to approach the standard. The **standard** is **zero defects**. Our goal is to be Best-in-Class in product, sales and service." (For a more detailed explanation, contact your Motorola Representative for a pamphlet of the Six Sigma Challenge.)

Quick insight into six sigma is obtained if we realize that a six sigma process has variability which is one half of the variation allowed (tolerance, spread) by the customer requirements (i.e. natural variation is one half of the customer specification range for a given characteristic). When six sigma is achieved, virtually zero defects are observed in the output of a process/product even allowing for potential process shifts (Figure 1).

Policies, objectives and five year plans are the mechanisms for communicating the key beliefs and measurable goals to all personnel and continuously keeping them in focus. This is done at the corporate, sector, group, division, and department levels.

The Analog Division, for example, evaluates performance to the corporate goals of **10 fold improvement by 1989; 100 fold improvement by 1991** and achievement of **six sigma capability by 1992** by utilizing indices such as Outgoing Electrical and Visual Mechanical Quality **(AOQ)** in terms of PPM (parts per million or sometimes given in parts per billion); **% of devices with zero PPM ; product quality returns** (RMR); number of processes/products with specified **capability indices (cp, cpk); six sigma capability roadmaps; failure rates for various reliability tests** (operating life, temperature humidity bias, hast, temperature cycling, etc.); **on-time delivery; customer product evaluation and failure analysis turnaround; cost of nonconformance; productivity improvement and personnel development**.

Figure 2 shows the improvement in electrical outgoing quality for analog products over recent years in a normalized form. Figure 3 shows the number of parts with zero PPM over a period of time.

**Documentation** control is an important part of **statistical process control. Process mapping** (flow charting etc. ) with documentation identified allows visualization and therefore optimization of the process. Figure 4 shows a portion of a flow chart for wafer fabrication. **Control plans** are an important part of Statistical Process Control, these plans identify in detail critical points where data for process control is taken, parameters measured, frequency of measurements, type of control device used, measuring equipment, responsibilities and reaction plans. Figure 5 shows a portion of a control plan for wafer fabrication. Six sigma progress is tracked by roadmaps based on the six sigma process, a portion of which is shown on Figure 6.

**On-time delivery** is of great importance, with the current emphasis on **just-in-time** systems. Tracking is done on an overall basis, and at the device levels.

**Figure 1. A Six Sigma Process Has Virtually Zero Defects Allowing for 1.5σ Shift**

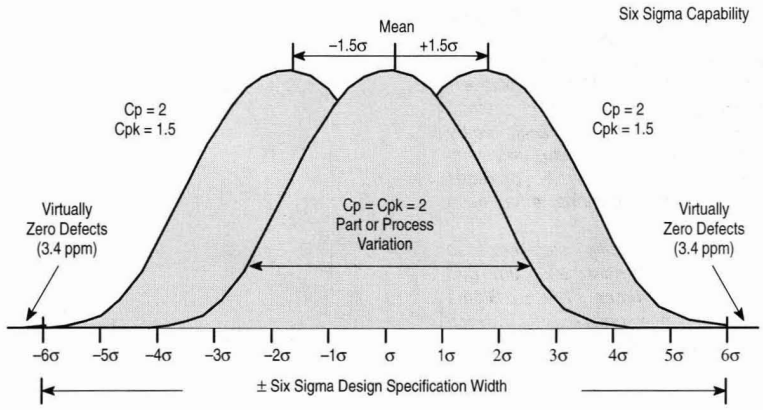

**Figure 2. Motorola Logic & Analog Technologies Group Electrical AOQ**

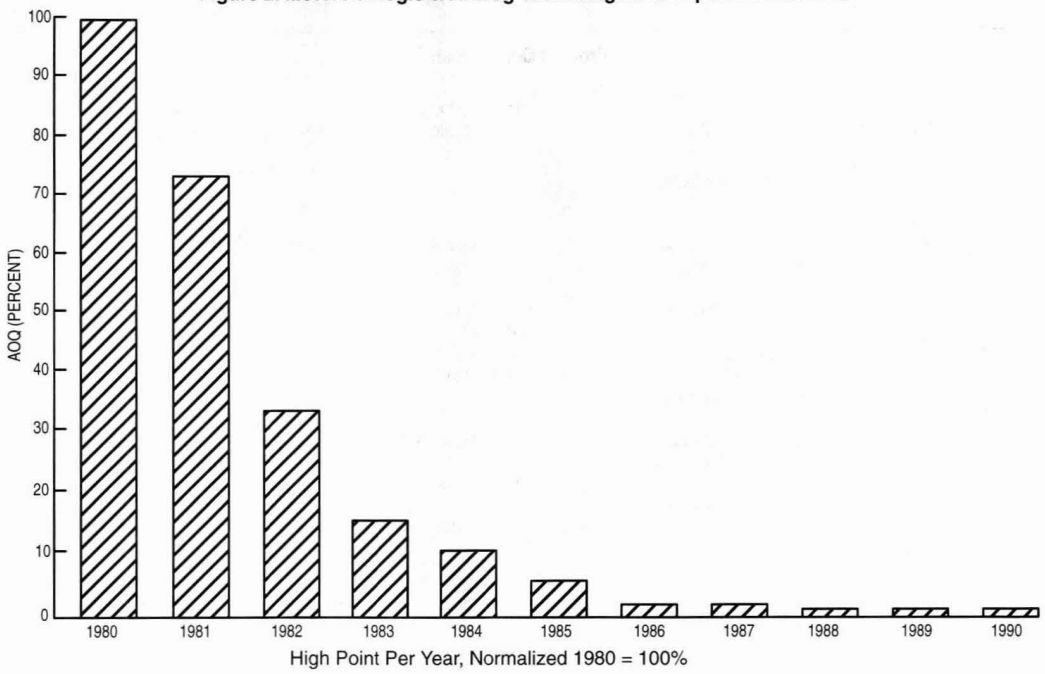


**Figure 3. Percentage of Parts with Zero PPM AOQ**

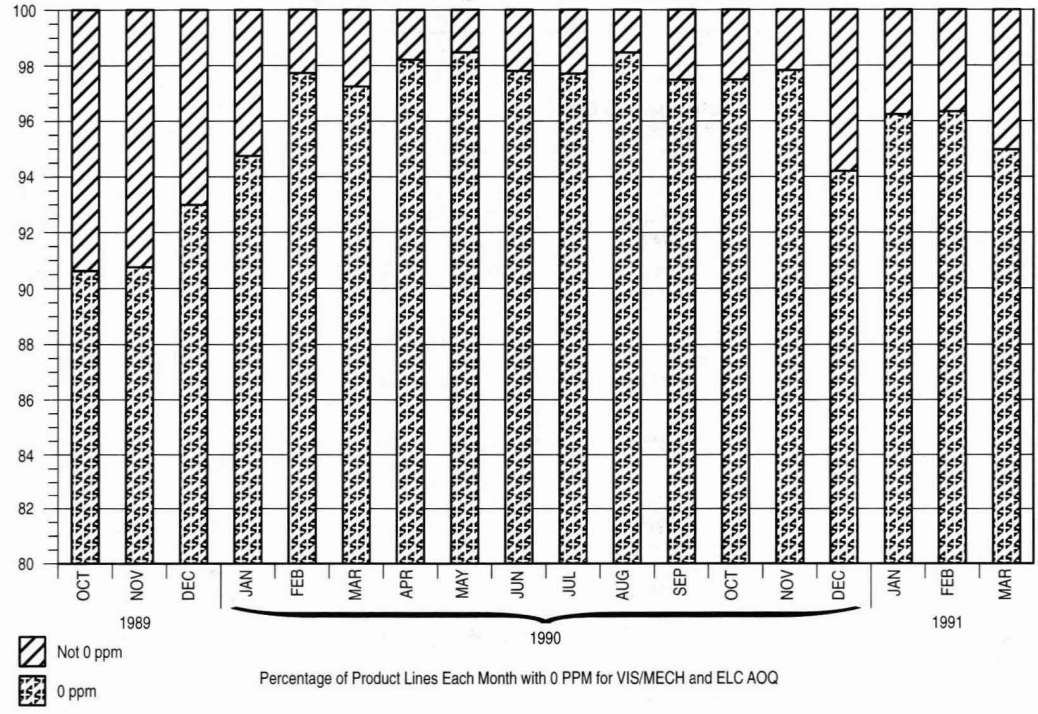


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**Figure 4. Portion of a Process Flow Chart From Wafer Fab, Showing Documentation Control and SPC**

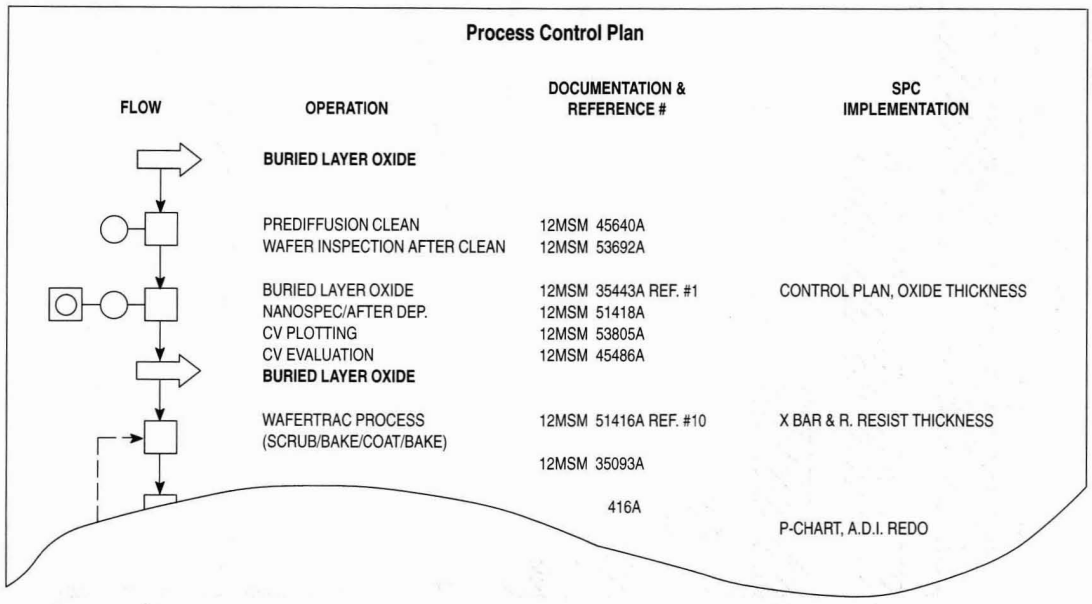



**Figure 5. Part of a Wafer Fab Control Plan, Showing Statistical Process Control Details**

| Characteristics: | Code | Description | Code | Description |
|---|---|---|---|---|
| | A | VISUAL DEFECTS | E | FILM SHEET RESISTANCE |
| | B | VISUAL DEFECTS . . . MICROSCOPE | F | REFRACTIVE INDEX |
| | C | PARTICLE . . . MONITOR | G | CRITICAL DIMENSION |
| | D | FILM THICKNESS | H | CV PLOT |

| Process Location | Ref. No. | Characteristic Affected | Part/Process Detail | Measurements Method | Analysis Methods | Frequency Sample Size | Reaction Plan: Point out of Limit (3) (4) |
|---|---|---|---|---|---|---|---|
| B.L. OXIDE | 1 | D | OXIDE THICKNESS | NANOMETRIC | CONTROL GRAPH | EVERY RUN 3 WFR/RUN | IMPOUND LOT (1) ADJUST TIME TO CENTER PROCESS PER SPEC |
| EPI | 2 | D | THICKNESS | DIGILAB | $\bar{X}$ R CHART | EVERY RUN 5 SITES/WFR | IMPOUND LOT (1) NOTIFY ENGR. |
| QA | | D | THICKNESS | DIGILAB | $\bar{X}$ R CHART | 1WFR/SHIFT 5 SITES/WFR | IMPOUND LOT (2) NOTIFY ENGR. |
| | | E | FILM RESISTIVITY | 4PT PROBE | $\bar{X}$ R CHART | EVERY RUN 5 SITES/WFR | IMPOUND LOT (1) NOTIFY ENGR. |
| QA | | E | FILM RESISTIVITY | 4PT PROBE | $\bar{X}$ R CHART | 1WFR/SHIFT 5 SITES/WFR | IMPOUND LOT (2) NOTIFY ENGR. |
| DEEP | | | | 4PT PROBE | MOVING R | EVERY LOT 1 CTRL WFR PER LOT | IMPOUND LOT NOTIFY ENGR. |

**Figure 6. Portion of Six Sigma (6σ) Roadmap Showing Steps to Six Sigma Capability**

| STEP | ±6σ Summary |
|---|---|
| 1. Identify critical characteristics | • Product Description<br>• Marketing<br>• Industrial Design<br>• R&D/Developmental Engineering<br>• Actual or Potential Customers |
| 2. Determine specified product elements contributing to critical characteristics | • Critical Characteristics Matrix<br>• Cause-and-Effect and Ishikawa Diagrams<br>• Success Tree/Fault Tree Analysis<br>• Component Search or Other Forms of Planned Experimentation<br>• FMECA (Failure Mode Effects and Critical Analysis) |
| 3. For each product element, determine the process step or process choice that affects or controls required performance | • Planned Experiments<br>• Computer-Aided Simulation<br>• TOP/Process Engineering Studies<br>• Multi-Vari Analysis<br>• Comparative Experiments |
| 4. Determine maximum (real) allowable tolerance for each and process | • Graphing Techniques<br>• Engineering Handbooks<br>• Planned Experiments<br>• Optimization, Especially Response Surface Methodology |

# Reliability Concepts

**Reliability** is the probability that an analog integrated circuit will succesfully perform its specified function in a given environment for a specified period of time. This is the classical definition of reliability applied to analog integrated circuits.

Another way of thinking about reliability is in relationship to quality. While **quality** is a measure of variability (extending to potential nonconformances-rejects) in the population domain, **reliability** is a measure of variability (extending to potential nonconformances-failures) in the population, time and environmental conditions domain. In brief, **reliability** can be thought of as **quality over time** and **environmental conditions**.

Ultimately, **product reliability** is a function of proper **understanding** of **customer requirements** and **communicating** them throughout design, product/process development, manufacturing and final product use. **Quality Function Deployment (QFD)** is a technique which may be used to facilitate identification of customer quality and reliability requirements and communicating them throughout an organization.

The most frequently used reliability measure for integrated circuits is the **failure rate expressed** in percent per thousand device hours (%/1000 hrs.). If the time interval is small the failure rate is called **Instantaneous Failure Rate** [$\lambda$ (t)] or "Hazard Rate." If the time interval is long (for example total operational time) the failure rate is called **Cumulative Failure Rate**.

The number of failures observed, taken over the number of device hours accumulated at the end of the observation period and expressed as a percent is called the point estimate failure rate. This however, is a number obtained from observations from a sample of all integrated circuits. If we are to use this number to estimate the failure rate of all integrated circuits (total population), we need to say something about the risk we are taking by using this estimate. A **risk** statement is provided by the **confidence level** expressed together with the failure rate. Mathematically, the failure rate at a given confidence level is obtained from the point estimate and the **CHI square** ($X^2$) distribution. (The $X^2$ is a statistical distribution used to relate the observed and expected frequencies of an event.) In practice, a reliability calculator rule is used which gives the failure rate at the confidence level desired for the number of failures and device hours under question.

As the number of device hours increases, our confidence in the estimate increases. In integrated circuits, it is preferred to make estimates on the basis of failures per 1,000,000,000 ($10^9$) device hours **(FITS)** or more. If such large numbers of device hours are not available for a particular device, then the point estimate is obtained by pooling the data from devices that are similar in process, voltage, construction, design, etc., and for which we expect to see the same failure modes in the field.

The environment is specified in terms of the temperature, electric field, relative humidity, etc., by an **Eyring** type equation of the form:

$$\lambda = Ae - \frac{\phi}{KT} \ldots e - \frac{B}{RH} \ldots e - \frac{C}{E}$$

where A, B, C, $\phi$ & K are constants, T is temperature, RH is relative humidity, E is the electric field, etc.

The most familiar form of this equation deals with the first exponential which shows an **Arrhenius type** relationship of the **failure rate** versus the **junction temperature** of integrated circuits, while the causes of failure generally remain the same. Thus we can test devices near their maximum junction temperatures, analyze the failures to assure that they are the types that are accelerated by temperature and then applying known acceleration factors, estimate the failure rates for lower junction temperatures. The Eyring or Arrhenius relationships should be used for failure rate projections in conjunction with proper understanding of failure modes, mechanisms and patterns such as infant mortality, constant failure rate (useful region) and wearout. For example if by design and proper process control infant mortality and useful period failures have been brought to zero and wearout failures do not start until, let us say, 30,000 hours at 125°C then failure rate projections at lower temperatures must account for these facts and whether the observed wearout failures occur at lower temperatures.

Figure 7 shows an example of a curve which gives estimates of failure rates versus temperature for an integrated circuit case study.

Arrhenius type of equation: $\lambda = Ae - \frac{\phi}{KT}$

where:
- $\lambda$ = Failure Rate
- A = Constant
- e = 2.72
- $\phi$ = Activation Energy
- K = Botzman's Constant
- T = Temperature in Degrees Kelvin

$$T_J = T_A + \theta_{JA} P_D \text{ or } T_J = T_C + \theta_{JC} P_D$$

where:
- $T_J$ = Junction Temperature
- $T_A$ = Ambient Temperature
- $T_C$ = Case Temperature
- $\theta_{JA}$ = Junction to Ambient Thermal Resistance
- $\theta_{JC}$ = Junction to Case Thermal Resistance
- $P_D$ = Power Dissipation

**Life patterns** (failure rate curves) for equipment and devices can be represented by an idealized graph called the **Bathtub Curve** (Figure 8).

There are three important regions identified on this curve. In Region A, the failure rate decreases with time and it is generally called **infant mortality** or early life failure region. In Region B, the failure rate has reached a relatively constant level and it is called **constant failure rate** or useful life region. In the third region, the failure rate increases again and it is called **wearout region**. Modern integrated circuits generally do not reach the wearout portion of the curve when operating under normal use conditions.

**Figure 7. Example of a Failure Rate versus Junction Temperature Curve**

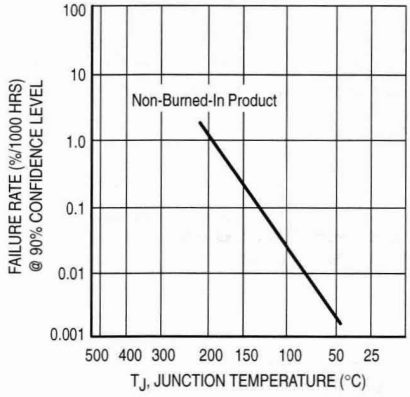
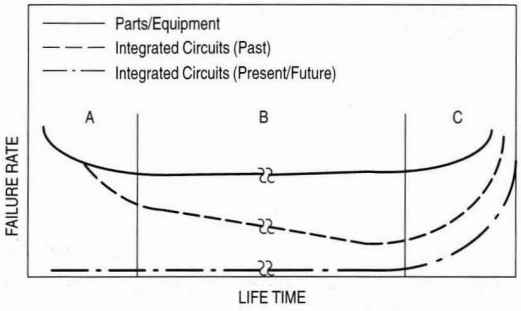



**Figure 8. A Model for Failure Distribution in Time Domain Bathtub Curve Model**




| Decreasing Failure Rate | Constant Failure Rate | Increasing Failure Rate |
|---|---|---|
| Infant Mortality<br>Burn-In<br>Manufacturing Variations<br>Workmanship Defects | Useful Life<br>Random (Chance) Defects (No Pattern; Occur Regularly) | Wearout<br>Material, Design, Process Limitations |
| Weibull<br>Log Normal<br>Gamma Distribution | Weibull<br>Exponential for Equipment<br>Log Normal for ICs | Weibull<br>Normal (Gaussian) |

The wearout portion of the curve can usually be identified by using highly accelerated test conditions. For modern integrated circuits, even the useful life portion of the curve may be characterized by few or no failures. As a result the bathtub curve looks like continuously declining (few failures, Figure 8, Curve B) or zero infant and useful period failures (constant failure rate until wearout, Curve C).

The **infant mortality** portion of the curve is of most interest to equipment manufacturers because of its impact on customer perception and potential warranty costs. In recent years the infant mortality portion of the curve for integrated circuits, and even equipment, has been drastically reduced

(Figure 8, Curve C). The reduction was accomplished by improvements in technology, emphasis on statistical process control, reliability modeling in design and reliability in manufacturing (wafer level reliability, assembly level reliability, etc.). In this respect many integrated circuit families have zero or near zero failure patterns until wearout starts.

Does a user still need to consider burn-in? For this question to be answered properly the IC user must consider the **target failure rate** of the equipment, **apportioned** to the components used, application environment, maturity of equipment and components (new versus mature technology), the impact of a failure (i.e. safety versus casual loss of entertainment), maintenance costs, etc. Therefore, if the IC user is going through these considerations for the first time, the question of burn-in at the component level should be discussed during a user-vendor interface meeting.

A frequently asked question is about the reliability differences between **plastic** and **hermetic** packaged integrated circuits. In general, for all integrated circuits including analog, the field removal rates are the same for normal use environments, with many claims of plastic being better because of its "solid block" structure.

The tremendous decrease of failure rates of plastic packages has been accomplished by **continuous improvements** in piece parts, materials and processes. Nevertheless, differences can still be observed under highly accelerated environmental stress conditions. For example, if a bimetallic (gold wire and aluminum metallization) system is used in plastic packages and they are placed on a high temperature operating life test (125°C) then failures in the form of opens, at the gold to aluminum interface, may not be observed until 30,000 hours of continuous operating life. Packages, whether plastic or hermetic, with a monometallic system (aluminum wire to aluminum metallization) will have no opens because of the absence of the gold to aluminum interface. As a result, a difference in failure rates will be observable.

Differences in failure rates between plastics and hermetics may also be observed if devices from both packaging systems are placed in a moist environment such as 85°C, 85% RH with bias applied. At some point in time plastic encapsulated ICs should fail since they are considered pervious by moisture, (the failure mechanism being corrosion of the aluminum metallization) while hermetic packages should not fail since they are considered impervious by moisture. The reason the word "should" was used is because advances in plastic compounds, package piece parts, encapsulation processes and final chip passivation have made plastic integrated circuits capable of operating more than 5000 hours without failures in an 85°C, 85% RH environment. Differences in failure rates due to internal corrosion between plastic and hermetic packages may not be observable until well after 5000 operating hours.

The aforementioned two examples had environments substantially more accelerated than normal life so the two issues discussed are not even a factor under normal use conditions. In addition, mechanisms inherent in hermetic packages but absent in plastics were not even considered here. Improved reliability of plastic encapsulated ICs has decreased demand of hermetic packages to the point where many devices are offered only in plastic packages. The user then should feel comfortable in using the present plastic packaging systems.

A final question that is asked by the IC user is, how can one be assured that the reliability of standard product does not degrade over time? This is accomplished by our emphasis on **statistical process control, in-line reliability** assessment and **reliability auditing** by periodic and strategic sampling and accelerated testing of the various integrated circuit device packaging systems. A description of these audit programs follows.

## Analog Reliability Audit Program

The reliability of a product is a function of proper understanding of the application and environmental conditions that the product will encounter during its life as well as design, manufacturing process and final use conditions. **Inherent reliability** is the reliability which a product would have if there were no imperfections in the materials, piece parts and manufacturing processes of the product. The presence of imperfections gives rise to reliability risks. **Failure Mode and Effects Analysis (FMEA)** is a technique for identifying, controlling and eliminating potential failures from the design and manufacture of the product.

Motorola uses **on-line** and **off-line** reliability monitoring in an attempt to prevent situations which could degrade reliability. **On-line** reliability monitoring is at the **wafer and assembly levels** while **off-line** reliability monitoring involves reliability assessment of the **finished product** through the use of **accelerated** environmental tests.

Continuous monitoring of the reliability of analog integrated circuits is accomplished by the **Analog Reliability Audit Program**, which is designed to compare the actual reliability to that specified. This objective is accomplished by periodic and strategic sampling of the various integrated circuit device packaging systems. The samples are tested by subjecting them to accelerated environmental conditions and the results are reviewed for unfavorable trends that would indicate a degradation of the reliability or quality of a particular packaging system. This provides the trigger mechanism for initiating an investigation for **root cause** and **corrective action**. Concurrently, in order to provide a minimum of interruption of product flow and assure that the product is fit for use, a lot by lot sampling or a non-destructive type 100% screen may be used to assure that a particular packaging system released for shipment does have the expected reliability. This rigorous surveillance is continued until there is sufficient proof (many consecutive lots) that the problem has been corrected.

The **Logic and Analog Technologies Group** has used reliability audits since the late sixties. Such programs have been identified by acronyms such as CRP (Consumer Reliability Program), EPIIC (Environmental Package Indicators for Integrated Circuits), LAPP (Linear Accelerated Punishment Program), and RAP (Reliability Audit Program).

Currently, the Analog Reliability Audit Program consists of a **Weekly Reliability Audit** and a **Quarterly Reliability Audit**. The Weekly Reliability Audit consists of rapid (short time) types of tests used to monitor the production lines on a real time basis. This type of testing is performed at the assembly/test sites worldwide. It provides data for use as an **early warning system** for identifying negative trends and triggering investigations for root cause and corrective actions.

The Quarterly Reliability Audit consists of long term types of tests and is performed at th U.S. Bipolar Analog Division Center. The data obtained from the Quarterly Reliability Audit is used to assure that the correlation between the short term weekly tests and long term quarterly tests has not changed and a new failure mechanism has not appeared.

A large data base is established by combining the results from the Weekly Reliability Audit with the results from the Quarterly Reliability Audit. Such a data base is necessary for estimating long term failure rates and evaluating potential process improvement changes. Also, after a process improvement change has been implemented, the Analog Reliability Audit Program provides a system for monitoring the change and the past history data base for evaluating the affect of the change.

## Weekly Reliability Audit

The Weekly Reliability Audit is performed by each assembly/test site worldwide. The site must have capability for final electrical and quality assurance testing, reliability testing and first level of failure analysis. The results are reviewed on a continuous basis and corrective action is taken when appropriate. The results are accumulated on a monthly basis and published.

The Reliability Audit test plan is as follows:

**Electrical Measurements:** Performed initially and after each reliability test, consist of critical parameters and functional testing at 25°C on a go-no-go basis.

**High Temperature Operating Life:** Performed to detect failure mechanisms that are accelerated by a combination of temperature and electric fields. Procedure and conditions are per MIL-STD-883, Method 1015 with an ambient temperature of 145°C for 40 hours or equivalent based on a 1.0 eV activation energy and the Arrhenius equation.

**Approximate Accelerated Factors**

| | 125°C | 50°C |
|---|---|---|
| 145°C | 4 | 4000 |
| 125°C | 1 | 1000 |

**Temperature Cycling/Thermal Shock:** Performed to detect mechanisms related to thermal expansion and contraction of dissimilar materials, etc. Procedures and conditions are per MIL-STD-883, Methods 1010 or 1011, with ambient temperatures of –65° to +150°C or –40° to +125°C (JEDEC-STD-22-A104), for a minimum of 100 cycles.

**Pressure Temperature Humidity (Autoclave):** Performed to measure the moisture resistance of plastic encapsulated packages. It detects corrosion type failure mechanisms due to free ionic contaminants that may have entered the package during the manufacturing processes. Conditions are per JEDEC-STD-22, Method 102, a temperature of 121°C, steam environment and 15 psig. The duration of the test is 96 hours (minimum).

**Analysis Procedure:** Devices failing to meet the electrical criteria after being subjected to an accelerated environment type test are verified and characterized electrically, then submitted for failure analysis.

## Quarterly Reliability Audit

The Quarterly Analog Reliability Audit Program is performed at the U.S. Bipolar Analog Division Center. This testing is designed to assure that the correlation between the short term weekly tests and the longer quarterly tests has not changed and that no new failure mechanisms have appeared. It also provides additional long term information for a data base for estimating failure rates and evaluation of potential process improvement changes.

**Electrical Measurements:** Performed initially and at interim readouts, consist of all standard DC and functional parameters at 25°C, measured on a go-no-go basis.

**High Temperature Operating Life Test:** Performed to detect failure mechanisms that are accelerated by a combination of temperature and electric fields. Procedure and conditions are per MIL-STD-883, Method 1015, with an ambient temperature of 145°C for 40 and 250 hours or equivalent, based on 1.0 eV activation energy and the Arrhenius equation.

**Approximate Accelerated Factors**

| | 125°C | 50°C |
|---|---|---|
| 145°C | 4 | 4000 |
| 125°C | 1 | 1000 |

**Temperature Cycling/Thermal Shock:** Performed to detect mechanisms related to thermal expansion and contraction, mismatch effects, etc. Procedure and conditions are per MIL-STD-883, Methods 1010 or 1011, with ambient temperatures of –65° to +150°C or –40° to +125°C (JEDEC-STD-22-A104) for 100, 500 and 1000 or more cycles, depending on the temperature range used. Temperature Cycling is used more frequently than Thermal Shock.

**Pressure Temperature Humidity (Autoclave):** Performed to measure the moisture resistance of plastic encapsulated packages. It detects corrosion type failure mechanisms due to free ionic contaminants that may have entered the package during the manufacturing processes. Conditions are per JEDEC-STD-22, Method 102, a temperature of 121°C, steam environment and 15 psig. The duration of the test is for 96 hours (minimum), with a 48 hour interim readout.

**Pressure Temperature Humidity Bias (PTHB; Biased Autoclaved):** This test measures the moisture resistance of plastic encapsulated packages. It detects corrosion type failure mechanisms due to free and bounded ionic contaminants that may have entered the package during the manufacturing processes, or they may be bound in the materials of the integrated circuit packaging system and activated by the moisture and the applied electrical fields. Conditions are per JEDEC-STD-22, Method 102, with bias applied, a temperature of 121°C, steam environment and 15 psig. This test detects the same type of failures as the Temperature Humidity Bias (85°C, 85% RH, with bias) test, only faster. The acceleration factor between PTHB and THB is between 20 and 40 times, depending on the type of corrosion mechanism, electrical field and packaging system.

**Highly Accelerated Stress Test (HAST)** is increasingly replacing the aforementioned **PTHB** test. The reason is that the **HAST** test allows control of pressure, temperature and

humidity independently of each other, thus we are able to set different combinations of temperature and relative humidity. The most frequently used combination is **130°C with 85% RH**. This has been related to THB (85°C, 85% RH) by an **acceleration factor of 20** (minimum). The ability to keep the relative humidity variable constant for different temperatures is the most appealing factor of the HAST test because it reduces the determination of the acceleration factor to a single Arrhenius type of relationship. Motorola has been phasing over to HAST testing since 1985.

**Temperature, Humidity and Bias (THB):** This test measures the moisture resistance of plastic encapsulated packages. It detects corrosion type failure mechanisms due to free and bounded ionic contaminants that may have entered the package during the manufacturing processes, or they may be bound in the materials of the integrated circuit packaging system and activated by moisture and the applied electrical fields. Conditions are per JEDEC-STD-22, Method 102 (85°C, 85% RH), with bias applied. The duration is for 1008 hours, with a 504 hour interim readout. The acceleration factor between THB (85°C, 85% RH with bias) and the 30°C, 90% RH is typically 40 to 50 times, depending on the type of corrosion mechanism, electrical field and packaging system.

**Analysis Procedure:** Devices failing to meet the electrical criteria after being subjected to an accelerated environment type test(s) are verified and characterized electrically, then they are submitted for root cause failure analysis and corrective action for continuous improvement.

# Applications and Product Literature

## In Brief . . .

*Motorola's Applications Literature provides guidance to the effective use of its semiconductor families across a broad range of practical applications. Many different topics are discussed — in a way that is not possible in a device data sheet — from detailed circuit designs complete with PCB layouts, through matters to consider when embarking on a design, to complete overviews of product families and their design philosophies.*

*Information is presented in the form of Application Notes, Article Reprints and detailed Engineering Bulletins.*

*Abstracts of all the applications documents are provided as a guide to their content; each abstract also shows the number of pages in the document, plus the origin of the article in the case of Article Reprints. Documents new to this issue are highlighted throughout.*

# Applications and Product Literature

*Indicates New Document

The application literature listed in this section has been prepared to acquaint the circuits and systems engineer with Motorola Linear integrated circuits and their applications. To obtain copies of the notes, simply list the publications number or numbers and send your request on your company letterhead to: Literature Distribution Center, Motorola Semiconductor Products Inc., P.O. Box 20912, Phoenix, Arizona 85036.

## Application Note Abstracts

**AN004E** ***Semiconductor Consideration for DC Power Supply Voltage Protector Circuits***

This paper addresses the requirements for the semiconductor sensing circuitry and SCR crowbar devices used in DC power supply over/under voltage protection schemes. (8pp)

**AN428** ***Automotive Direction Indicator with Short Circuit Detection Using the UAA1041***

Cold lamps and faulty wiring can cause false operation when using the UAA1041 Automotive Direction Indicator IC. This note provides simple solutions. (3pp)

**AN531** ***MC1596 Balanced Modulator***

The MC1596 Monolithic Balanced Modulator is a versatile HF communications building block. It functions as a broadband, double-sideband suppressed-carrier balanced modulator without the need for transformers or tuned circuits. This article describes device operation and biasing, and gives circuit details for typical modulator/demodulator applications in AM, SSB and suppressed-carrier AM. Additional uses as an SSB Product Detector, AM Modulator/Detector, Mixer, Frequency Doubler, Phase Detector and others are also illustrated. An appendix gives detailed AC and DC analysis. (13pp)

**AN535** ***Phase-Locked-Loop Design Fundamentals***

The fundamental design concepts for phase-locked-loops implemented with integrated circuits are outlined. The necessary equations required to evaluate the basic loop performance are given in conjunction with a brief design example. (12pp)

**AN545A** ***Television Video IF Amplifier Using Integrated Circuits***

This applications note considers the requirements of the video IF amplifier section of a television receiver, and gives working circuit schematics using integrated circuits which have been specifically designed for consumer oriented products. The integrated circuits used are the MC1350, MC1352, and the MC1330. (12pp)

**AN559** ***A Single Ramp Analog-to-Digital Converter***

A simple single ramp A/D converter which incorporates a calibration cycle to ensure an accuracy of 12 bits is discussed. The circuit uses standard ICs and requires only one precision part — the reference voltage used in the calibration. This converter is useful in a number of instrumentation and measurement applications. (10pp)

**AN569** ***Transient Thermal Resistance — General Data and its Use***

Data illustrating the thermal response of a number of semiconductor die and package combinations are given. Its use, employing the concepts of transient thermal resistance and superposition, permit the circuit designer to predict semiconductor junction temperature at any point in time during application of a complex power pulse train. (16pp)

**AN587** ***Analysis and Design of the Op Amp Current Source***

Voltage-controlled current sources based on operational amplifiers are both versatile and accurate, yet the quality of op amps required is unimportant. This note develops general expressions for basic transfer function and output impedance, and shows that simplified equations give a very accurate description of actual circuit performance. Includes a section on analysis of the errors that result from changes in circuit parameters and temperature. (7pp)

**AN703** ***Designing Digitally-Controlled Power Supplies***

This application note shows two design approaches; a basic low voltage supply using an inexpensive MC1723 voltage regulator and a high current, high voltage, supply using the MC1466 floating regulator with optoelectronic isolation. Various circuit options are shown to allow the designer maximum flexibility in an application. (9pp)

**AN708A** ***Line Driver and Receiver Considerations***

This report discusses many line driver and receiver design considerations such as system description, definition of terms, important parameter measurements, design procedures and application examples. An extensive line of devices is available from Motorola to provide the designer with the tools to implement the data transmission requirements necessary for almost every type of transmission system. (18pp)

**AN719** ***A New Approach To Switching Regulators***

This article describes a 24 V, 3.0 A switching mode supply. It operates at 20 kHz from a 120 V AC line with an overall efficiency of 70%. New techniques are used to shape the load line. The control circuit uses a quad comparator and an opto-coupler and features short circuit protection. (12pp)

**AN740** ***The Design of an N-Channel 16k x 16 Bit Memory System for the PDP-11***

This application note describes the design and construction of a mainframe memory system with MCM6605 N-channel MOS memories. Topics included are: the interface to the PDP-11, refresh control and bookkeeping, timing control logic for the memories, memory system considerations and organization. The memory also features new integrated circuits that reduce package count and enhance memory system performance. (16pp)

**AN781A** ***Revised Data Interface Standards***

Revised data interface standards allow higher data rates and longer cables. This note provides an overview and comparison of the electrical and performance characteristics of RS232-C, RS422, RS423, RS449 and RS485. Includes a list of appropriate Motorola drivers and receivers with performance summaries. (6pp)

**AN829** ***Application of the MC1374 TV Modulator***

The MC1374 was designed for use in applications where separate audio and composite video signals are available, which need converting to a high quality VHF television signal. It's ideally suited as an output device for subscription TV decoders, video disk and video tape players. (12pp)

**AN879** ***Monomax: Application of the MC13001 Monochrome Television Integrated Circuit***

This application note presents a complete 12″ black and white line-operated television receiver, including artwork for the printed circuit board. It is intended to provide a good starting point for the first-time user. Some of the most common pitfalls are overcome, and the significance of component selections and locations are discussed. (12pp)

**AN917** ***Reading and Writing in Floppy Disk Systems Using Motorola Integrated Circuits***

The floppy disk system has become a widely used means for storing and retrieving both programs and data. A floppy disk drive requires precision controls to position and load the head as will as defined read/write signals in order to be a viable system. This application note describes the use of the MC3469 and MC3471 Write Control ICs and the MC3470 Read Amplifier which provide the necessary head and erase control, timing functions, and filtering. (16pp)

**AN920** ***Theory and Applications of the MC34063 and μA78S40 Switching Regular Control Circuits***

This paper describes in detail the principle of operation of the MC34063 and μA78S40 switching regulator subsystems. Several converter design examples and numerous applications circuits with test data are included. (38pp)

**AN921** ***Horizontal APC/AFC Loops***

The most popular method used in modern television receivers to synchronize the line frequency oscillator is the phase locked loop. The operating characteristics and parameters of the loops are discussed. (19pp)

**AN932** ***Application of the MC1377 Color Encoder***

The MC1377 is an economical, high quality, RGB encoder for NTSC or PAL applications. It accepts RGB and composite sync inputs, and delivers a 1.0 Vp-p composite NTSC or PAL video output into a 75 Ω load. It can provide its own color oscillator and burst gating, or it can easily be driven from external sources. Performance virtually equal to high-cost studio equipment is possible with common color receiver components. (12pp)

***AN954** ***A Unique Converter Configuration Provides Step–Up/Down Functions***

The use of switching regulators in new portable equipment designs is becoming more pronounced over that of linear regulators. This is primarily due to the need for reductions in size and weight which dictate an ever increasing demand for higher power conversion efficiency from a battery pack. When designing at the board level it sometimes becomes necessary to generate a constant output voltage that is less than that of the battery. The step–down circuit is presented that will perform this function efficiently. However, as the battery discharges, its terminal voltage will eventually fall down below the desired output, and in order to utilize the remaining battery energy a step–up circuit is also presented.

**AN957** ***Interfacing the Speakerphone to the MC34010/11/13 Speech Networks***

Interfacing the MC34018 speakerphone circuit to the MC34010 series of telephone circuits is described in this application note. The series includes the MC34010, MC34011, MC34013, and the new "A" version of each of those. The interface is applicable to existing designs, as well as to new designs. (12pp)

**AN958** ***Transmit Gain Adjustments for the MC34014 Speech Network***

The MC34014 telephone speech network provides for direct connection to an electret microphone and to Tip and Ring. In between, the circuit provides gain, drive capability, and determination of the ac impedance for compatibility with the telephone lines. Since different microphones have different sensitivity levels, different gain levels are required from the microphone to the Tip and Ring lines. This application note will discuss how to change the gain level to suit a particular microphone while not affecting the other circuit parameters. (2pp)

**AN959** ***A Speakerphone with Receive Idle Mode***

The MC34018 speakerphone system operates on the principle of comparing the transmit and receive signals to determine which is stronger, and then switching the circuit into that mode. (2pp)

**AN960** ***Equalization of DTMF Signals Using the MC34014***

This application note will describe how to obtain equalization (line length compensation) of the DTMF dialing tones using the MC34014 speech network. (2pp)

**AN968** ***A Digital Voice/Data Telephone Set***

This design provides standard analog telephone functions while simultaneously transmitting 9600 baud asynchronous data. It is based on Motorola's MC145422/26 UDLT family of voice/data ICs which provide 80 kbps full-duplex synchronous communication over distances up to 2 km. The circuit includes a Codec/filter, Data Set Interface and pulse/tone dialer. (7pp)

**AN976** ***A New High Performance Current Mode Controller Teams Up with Current Sensing Power MOSFETs***

A new current mode control IC that interfaces directly with current sensing power MOSFETs is described. Its second generation architecture is shown to provide a variety of advantages in current mode power supplies. The most notable of these advantages is a "lossless" current sensing capability that is provided when used with current sensing MOSFETs. The discussion includes subtle factors to watch out for in practical designs, and an applications example. (8pp)

**AN980** ***VHF Narrowband FM Receiver Design Using the MC3362 and the MC3363 Dual Conversion Receivers***

The MC3362 and MC3363 narrowband FM dual conversion receivers feature excellent VHF performance with low power drain, making them ideal for cordless telephones, narrowband voice and data receivers and RF security devices. This note provides a detailed description of the operation of the two devices, plus circuits and descriptions for four applications: a Single Channel VHF FM Narrowband Receiver; a Ten Channel Frequency Synthesized Cordless Telephone Receiver; a 256 Channel Frequency Synthesized Two-Meter Amateur Band Receiver; and a Single Chip Weather Band Receiver. (14pp)

**AN983** ***A Simplified Power Supply Design Using the TL494 Control Circuit***

This application note describes the operation and characteristics of the TL494 Switchmode™ Voltage Regulator and shows its application of a 400 W offline power supply.

The TL494 is a fixed-frequency pulse width modulation control circuit, incorporating the primary building blocks required for the control of a switching power supply. (5pp)

**AN1002** ***A Handsfree Featurephone Design Using the MC34114 Speech Network and the MC34018 Speakerphone ICs***

A comprehensive application note which develops a full featurephone circuit using the MC34114 Speech Network, the MC34018 Speakerphone IC and the MC145412 Dialer. Functions include 10 number memory pulse/tone dialer, tone ringer, mike mute and line length compensation for both handset and speakerphone operation. Options include line-powered circuit, line-powered circuit with booster for long lines, and external supply-powered. Includes glossary of telephone terms. (18pp)

**AN1003** ***A Featurephone Design, with Tone Ringer and Dialer, Using the MC34118 Speakerphone IC***

This application note describes how to add a handset, dialer and tone ringer to the MC34118 speakerphone circuit. Although any one of several speech networks could be used as an interface between the MC34118 and the phone line this application note covers the case where simplicity and low cost are paramount. Two circuits are developed in this discussion: line-powered and supply-powered versions. (13pp)

**AN1004** ***A Handsfree Featurephone Design Using the MC34114 Speech Network and the MC34118 Speakerphone ICs***

Complete designs for a featurephone providing 10 number memory, pulse or tone dialling, tone ringer, microphone muting, and line length compensation for both handset and speakerphone operation. Includes line-powered, line-powered plus long-line booster, and supply-powered versions. The MC34114 interfaces with tip and ring and provides 2-to-4 wire conversion. (18pp)

**AN1006** ***Linearize the Volume Control of the MC34118 Speakerphone***

A single resistor added to the volume control potentiometer in an MC34118 speakerphone application will almost perfectly linearize the control law. (1pp)

**AN1016** ***Infrared Sensing and Data Transmission Fundamentals***

Many applications need electrical isolation, remote control or position sensing. Infrared light provides an excellent solution due to its low cost, ease of use, availability of components, and freedom from the licensing and interference concerns of RF techniques. This note is a brief but informative reference on the design principles for IR systems, including a selection of receiver circuits. (6pp)

**AN1019** ***NTSC Decoding Using the TDA3330, with Emphasis on Cable In/Cable Out Operation***

The TDA3330 is a Composite Video to RGB Color Decoder originally intended for PAL and NTSC color TV receivers and monitors — so its data sheet concentrates on picture tube drive. This practical application note supplements the data sheet by providing circuits for video cable drive as used in video processing, frame store and other specialized applications, and expands on TDA3330 functional details. Includes PCB artwork and layout of an evaluation board. (8pp)

**AN1040** ***Mounting Considerations for Power Semiconductors***

The operating environment is a vital factor in setting current and power ratings of a semiconductor device. Reliability is increased considerably for relatively small reductions in junction temperature. Faulty mounting not only increases the thermal gradient between the device and its heatsink, but can also cause mechanical damage. This comprehensive note shows correct and incorrect methods of mounting all types of discrete packages, and discusses methods of thermal system evaluation. (20pp)

**AN1044** ***The MC1378 — A Monolithic Composite Video Synchronizer***

The MC1378 provides an interface between a remote composite color video source and local RGB. On-chip circuitry can lock a local computer to the remote source, switching between local and remote signals to generate composite video overlays. This detailed note describes local and remote operation; picture-in-picture applications and the design of test fixtures to help system development. Printed circuit artwork for an evaluation board is provided. The NTSC/PAL color encoder is similar to the MC1377, discussed in detail in AN932. (13pp)

**AN1046** ***Three Piece Solution for Brushless Motor Control Design (Rev. 1)***

Until recently, the design of compact but comprehensive circuits taking full advantage of the unique attributes of brushless DC motors has been difficult, while available power transistors have not always performed as well as is necessary for the application. This high-performance three-chip solution couples the rugged MPM3003 three phase MOSFET bridge (in a 12-pin power package) with the MC33035 Brushless DC Motor Adapter. Design is simplified, board area reduced. Full circuit, parts list, and discussion of practical considerations. (10pp)

***AN1065** ***Use of the MC68HC68T1 Real–Time Clock with Multiple Time Bases***

While this Application Note is primarily about the MC68HC68T1 clock/calendar device, it also provides an example of the application of two Motorola Analog ICs: the MC34160 Microporcessor Voltage Regulator and Supervisory Circuit and the MC34164 Undervoltage Sensing Circuit. The MC34160 provides a regulated 5.0 V supply, plus power warning and reset outputs to the MCU. The MC34164 assures that the MCU is held in reset when the supply voltage is too low for the MC34160 to operate correctly.

**AN1077** ***Adding Digital Volume Control To Speakerphone Circuits***

Describes how to control speakerphone volume from UP and DOWN switches in place of the more usual potentiometer. Includes a fully annotated circuit using only three standard CMOS ICs and no critical components. (4pp)

**AN1078** ***New Components Simplify Brush DC Motor Drives***

A variety of new components simplify the design of brush motor drives. One is a brushless motor control IC which is easily adapted to brush motors. Others include multiple Power MOSFETs in H-Bridge configuration, a new MOS turn-off device, and gain-stable opto level shifters. Several circuits illustrate how the new devices can be used in practical motor drives, in particular to control speed in both directions and operate from a single power supply. (6pp)

**AN1080** ***External-Sync Power Supply with Universal Input Voltage Range for Monitors***

As the resolution of color monitors increases, the performance and features of their power supplies becomes more critical. EMI/RFI generated by switching power supplies can adversely affect resolution if switching frequency is not synchronized to horizontal scanning frequency. This 90 W flyback switching supply demonstrates the use of new high performance devices in a low cost design, and includes a new universal input voltage adapter. (20pp)

**AN1081** ***Minimize the "pop" in the MC34119 Low Power Audio Amplifier***

Sometimes a "pop" is heard in the loudspeaker when the MC34119 audio amplifier is re-enabled. There are several possible causes, but this note offers a simple and low cost remedy to satisfy the most demanding user. (3pp)

**AN1101** ***One-Horsepower Off-Line Brushless Permanent Magnet Motor Drive***

Brushless Permanent Magnet (BPM) motors (brushless DC motors) using MOSFET inverters are common in low voltage, variable speed applications such as disk drives. Higher voltage off-line applications can also use the same technology, but there have been problems in designing a reliable, low cost high side driver and understanding the more subtle effects of diode snap and PCB layout. This one-horsepower off-line BPM motor drive board uses opto-isolators and a special MOSFET turn-off IC for level translation. Includes PCB artwork and parts list, and a discussion of the theory. (10pp)

**AN1108** ***Design Considerations for a Two Transistor, Current Mode Forward Converter***

This design for a 150 W, 150 kHz, two transistor, current mode forward converter illustrates solutions for noise control, feedback circuit analysis and magnetic component design — topics that often create the most problems for designers. Improved Schottky rectifiers, power MOSFETs and optocouplers — and their effects on switchmode power supply design — are also considered. Includes circuit, analysis, parts list and theoretical discussion. (11pp)

**AN1122** ***Running the MC44802A PLL Circuit***

The MC44802A provides the Phase-Locked-Loop (PLL) portion of a tuning circuit intended for TV, FM radio and set-top converter applications up to 1.3 GHz; a complete tuning circuit is formed by adding a Voltage Controlled Oscillator (VCO) and mixer. The data sheet recommends use of an MCU for sending the control bytes that set the tuning frequency. This note describes a serial ($I^2C$) interface with an MC68HC11E9 in a tuner design — the information is sufficiently general to allow almost any MCU to be used. Includes M68HC11 program listing. (12pp)

**AN1126** ***Evaluation Systems for Remote Control Devices on an Infrared Link***

The availability at low cost of remote control devices and infrared communication links provides opportunities in many application areas. This note gives information for constructing the basic building blocks to evaluate both IR links and the most popular remote control devices. Schematics and single-side PCB layouts are presented that should enable the designer quickly to put together a basic control link and evaluate its suitability for a given application in terms of data rate, effective distance, error rate and cost. Sources for special parts are also given. (10pp)

**AN1203** ***A Software Method for Decoding the Output from the MC14497/MC3373 Combination***

Infrared communication is now widely used as a simple and effective means of remote control over short distances. A variety of encoding methods is used, including the biphase scheme implemented by the MC14497, a complete building block for IR data transmission. The MC3373 is a companion receiver chip to the MC14497, providing front-end processing to interface a photo detector to a TTL level. This note describes the decoding of the data at the output of the MC3373, along with software listings for the MC68HC11 and the MC68HC05. (5pp)

**AN1300** ***Interfacing Microcomputers to Fractional Horsepower Motors***

In fractional horsepower motion control systems, command signals are usually now generated by a microprocessor or digital signal processor, while power is applied with MOSFETs. The interface between the two can still present difficulties; for small motors it will be, typically, 5.0 V logic to complementary P-Channel/N-Channel MOSFET H-bridges. A number of factors need to be considered, including diode snap, group bounce, noise suppression and locking out invalid inputs. The design discussed here is embodied in evaluation board DEVB103. (8pp)

**AN1301** ***Interfacing Analog Inputs to Fractional Horsepower Motors***

In many types of systems it is desirable to control motor speed with an analog signal. Even in digital systems, it is often cost effective to generate an analog signal from static speed control bits or a lower frequency PWM signal than to use a more expensive MCU capable of generating a 20 kHz+ PWM signal directly. Although recent developments have simplified analog input conversion and power MOSFET outputs, the interface between signal processing circuits and power outputs is still far from simple. This note discusses the issues using the DEVB118 evaluation board as an example design. (9pp)

**AN1306** ***Thermal Distortion in Video Amplifiers***

Thermal distortion is a problem in many high resolution video amplifiers. It occurs when there are instantaneous power changes in the transistor stages, and if the problem remains uncompensated, this leads to the visual effect known as smearing. This note discusses what smearing is, what causes thermal distortion, how to measure it, and how to compensate for it. (5pp)

**AN1307** ***A Simple Pressure Regulator Using Semiconductor Pressure Transducers***

Semiconductor pressure transducers offer an economical means of achieving high reliability and performance in pressure sensing applications. The completely integrated MPX5100 (0 psi to 15 psi) series provides a temperature compensated, high level linear output suitable for interfacing directly with many linear control systems. This circuit illustrates how the MPX5100 can be used with a simple pressure feedback system based on the MC33033 Brushless Motor Controller to establish pressure regulation. Includes circuit diagram and PCB artwork. (7pp)

***AN1315** ***An Evaluation System Interfacing the MPX2000 Series Pressure Sensors to a Microprocessor***

Outputs from compensated and calibrated semiconductor pressure sensors such as the MPX2000 series devices are easily amplified and interfaced to a microprocessor. Design considerations and the description of an evaluation board using a simple analog interface connected to a microprocessor is presented here. (21pp)

**AN1510** ***A Mode Indicator for the MC34118 Speakerphone Circuit***

Within the MC34118 are two comparators driven by the level detectors which are sensing the speech signals (see MC34118/D Data Sheet, Figure 24). The comparators' outputs drive the attenuator control block which sets the operating mode. (2pp)

***AN1539** ***An IF Communication Circuit Tutorial***

This article is intended to be a tutorial on the use of IF communication integrated circuits. The ISM band channel bandwidths and the Motorola MC13156 are used within this article as a platform for discussion. An examination of the devices topology is provided along with a discussion of the classical parameters critical to the proper operation of any typical IF device. The parameters reviewed are impedance matching the mixer, selecting the quad tank and filters and concluding with a overview of bit error rate testing for digital applications. Upon completion, the reader will have a better understanding of IF communications basics and will be able to specify the support components necessary for proper operation of these devices. (8pp)

***AN1544** ***Design of Continuously Variable Slope Delta Modulation Communication Systems***

Delta modulation is a simple and robust method of A/D conversion in systems requiring serial digital communications of analog signals. Delta modulation is limited by the anlaog input frequency and amplitude processed with any given circuit configuration; *i.e.*, the higher the clock frequency, the better the modulation quality (the clock frequency should be typically 9.6 kHz to 64 kHz for voice applications). Delta modulaton has the advantage that signal to noise ratios do not vary with distance in digital transmission and multiplexing, and the switching and repeating hardware is more economical than with purely analog systems. This paper is intended to give practical guidance in designing an optimum deltamod configuration for the most common voice applications using a Continuously Variable Slope Delta Modulator/Demodulator, MC34115 or MC3418, and provide some useful SNR performance information. (20pp)

***AN1548** ***Guidelines for Debugging the MC44011 Video Decoder***

Normally, the implementation of the MC44011 Multistandard video decoder is fairly simple in that there are no external adjustments, or critical components, to deal with. However, since this IC contains several interrelated functions and a substantial amount of programmability, debugging an improperly working circuit can sometimes be daunting. The purpose of this document is to provide a procedure for debugging and checking the operation of this IC, and an indication of what to expect at some of the various pins. (8pp)

***AN1575** ***Worldwide Cordless Telephone Frequencies***

This application note contains a listing of the worldwide cordless telephone frequencies by country. These tables reference application information provided in the MC13109, MC13110, and MC13111 Universal Cordless Telephone Subsystem Integrated Circuit Technical Data Sheets. Channel number, $T_X$ channel frequency, 1st LO frequency, and $T_X$ and $R_X$ divider values are listed in this application note. (8pp)

**ANE424** ***50 W Current Mode Controlled Offline Switch Mode Power Supply Working over 50% Duty Cycle using the UC3842A***

Switchmode power supplies based on flyback architecture and voltage-controlled PWM techniques are well established. This note describes a way of improving their dynamic characteristics using a Current Controlled PWM technique. A dedicated bipolar IC, the UC3842A Off-Line Current Mode PWM Controller, performs the current control, regulation and safety features. Full analysis of transformer and other components, plus discussion of the instability inherent in the current control mode. (27pp)

**ANHK02** ***Low Power FM Transmitter System MC2831A***

This application note provides information concerning the MC2831A, a one-chip low-power FM transmitter system designed for FM communication equipment such as FM transceivers, cordless telephones, remote control and RF data link. (16pp)

## Article Reprint Abstracts

**AR301** ***Solid State Devices Ease Task of Designing Brushless DC Motors***

Brushless fractional-horsepower DC motors are gaining in popularity over brush type motors. Their characteristics are similar but they avoid the practical problems associated with brushes. In the past control complexity has made them less attractive, but dedicated control ICs like the MC33034, plus current-sensing power MOSFETs, mean that much of the control and protection electronics is available off the shelf. (*EDN*, 3 September 1987) (7pp)

**AR323** ***Managing Heat Dissipation in DPAK Surface Mount Power Packages***

Physically smaller than a lead-formed TO-220, the DPAK was introduced to accommodate larger die than in previously available SM packages like the SOT-223. But larger die implies increased heat dissipation. New board materials and good circuit design ensure that DPAK power MOSFETs can readily switch at their full pulse current ratings.
(*Powertechnics*, December 1988) (4pp)

**AR340** ***The Low Forward Voltage Schottky***

As feature sizes are scaled down in very high density circuits, it will be necessary for the standard power supply voltage to be reduced from 5.0 V to 3.3 V within the next few years to avoid degrading performance in the new devices. Also, greater power supply efficiency will be required if the power supply is not to occupy a disproportionate amount of the total system volume. Since the major power loss in switching power supplies is in the output rectification circuits, more efficient rectifiers are needed. Schottky rectifier technology shows the greatest potential. (*Powertechnics*, May 1990) (3pp)

## Engineering Bulletin Abstracts

**EB27A** ***Get 300 Watts EPE Linear Across 2 to 30 MHz from this Push-Pull Amplifier***

Includes circuit, PCB artwork and layout for a 300 W push-pull linear amplifier based on two MRF422s, designed to operate over the 2.0 MHz to 30 MHz band. An MC1723 voltage regulator is used as a bias supply. (4pp)

**EB85A** ***Full-Bridge Switching Power Supplies***

A useful selection chart presenting preferred Bipolar, power MOSFET, Rectifier and Control devices for various areas of typical 500 W to 1000 W full-bridge switching power supplies. (1p)

**EB112** ***The Application of a Telephone Tone Ringer as a Ring Detector***

Telephone ringers are driven by high voltage, low frequency AC signals which are superimposed on the 48 V DC Tip-Ring feed voltage. An electronic ring detector must sense the presence of an AC signal on the line and produce a dielectrically isolated logic level to the system processor. (2pp)

**EB123** ***A Simple Brush Type DC Motor Controller***

A simple and cost effective way to drive brush type DC motors is to use power MOSFETs with a Brushless DC Motor Control IC. The low cost MC33033 controller and integrated 8.0 A/100 V MPM3002 H-bridge combine to give a minimum parts count brush motor drive. (2pp)

**EB124** ***MOSFETs Compete with Bipolars in Flyback Power Supplies***

Power MOSFETs with 400 V to 500 V breakdown ratings are widely used in multiple-transistor off-line power supplies. Now they can be used in flyback supplies as well, as breakdown voltages are extended to 1000 V. A discussion of the advantages and disadvantages, illustrated with typical 100 W MOSFET and Bipolar designs. (2pp)

**EB126** ***Ultra-Rapid Nickel-Cadmium Battery Charger***

Charging NiCad batteries is a particular problem when their voltage exceeds the voltage of the available charging source. The ultra-fast charger presented here is capable of charging eight to twelve 1.5 V batteries at 1.2 A to 1.8 A in 30 to 45 minutes from a 10 V to 14 V source — a feat made possible by the use of new sintered electrode technology by battery manufacturers. Includes PC artwork and layout. (3pp)

**EB128** ***Simple, Low-Cost Motor Controller***

This low cost DC motor controller uses the cost effective MPM3002 SENSEFET-based H-Bridge, plus the MC34060 PWM IC. It is capable of driving a 1/3 HP, permanent magnet 90 V DC motor, and includes dynamic braking and Soft-Start. (2pp)

**EB142** ***The MOSFET Turn-Off Device — A New Circuit Building Block***

Technical developments have lead to a variety of discrete devices using circuit integration to reduce system cost and board space, while offering some performance improvement over conventional solutions. The first of these new components — dubbed SMALLBLOCK™ — is a building block that simplifies and reduces the component cost of an active gate-turn-off network for current-source driven MOSFETs. It is available in TO-92, SOT-23 and SOT-223 packages. (8pp)

## Product Literature

| | |
|---|---|
| DL136/D | *Telecommunications Device Data* |
| HB206 | *Linear & Switchmode Voltage Regulator Handbook* (See Back of Chapter 3) (Out of Print) |
| SG56/D | *TMOS Power MOSFET Selector Guide / Cross Reference* |
| SG73/D | *Master Selection Guide* |
| SG79/D | *SWITCHMODE — A Designer's Guide for Switching Power Supply Circuits and Components* |
| SG96/D | *Linear/Interface ICs Selector Guide Selector Guide and Cross Reference* |
| SG98/D | *Linear Telecom Cross Reference* |
| SG127/D | *Surface Mount Products Selector Guide* |
| SG368/D | *Video Capture Chip Sets Selector Guide* (See Front of Chapter 9) |
| SG410/D | *Applications & Product Literature Selector Guide / Cross Reference* |

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**DL128/D**